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FINAL ENGINEERING REPORT

DEVELOPMENT OF THE
PILOT WARNING INSTRUMENT (PWI)

Report No. RLF-3852-1
May 1960 - February 1961

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MOTOROLA INC.
Systems Research Laboratory
Riverside, California
February 1962

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Report No. RLF-3852-1
May 1960 - February 1961

Prepared for:

**Federal Aviation Agency
Bureau of Research and Development
Washington 25, D. C.**

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**MOTOROLA INC.
Systems Research Laboratory
Riverside, California**

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PILOT WARNING INSTRUMENT (PWI)

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FINAL ENGINEERING REPORT

DEVELOPMENT OF THE PILOT WARNING INSTRUMENT (PWI)

1. ABSTRACT

The theory and operation of a metric wave pilot warning instrument are presented in detail. Each aircraft transmits its altitude as frequency modulation at 135.54 megacycles. This interrogating pulse of 500 microseconds is transmitted omnidirectionally and reply is made by all coaltitude aircraft with a 15 microseconds pulse at 135.54 megacycles. The direction of the reply is determined by receiving the signal on three spaced antennas and comparing the phase. Crystal control is used for both transmitter and receiver stability. The distance and angle of arrival are presented on a multiple sector display. Range is presented in 5 mile segments to 25 miles and angle in 6, 30° segments for the forward 180°. Information content is adequate for the full 360° but was not included for reasons of economy. The several individual circuits and functions are discussed adequately for maintenance of the equipment during evaluation and

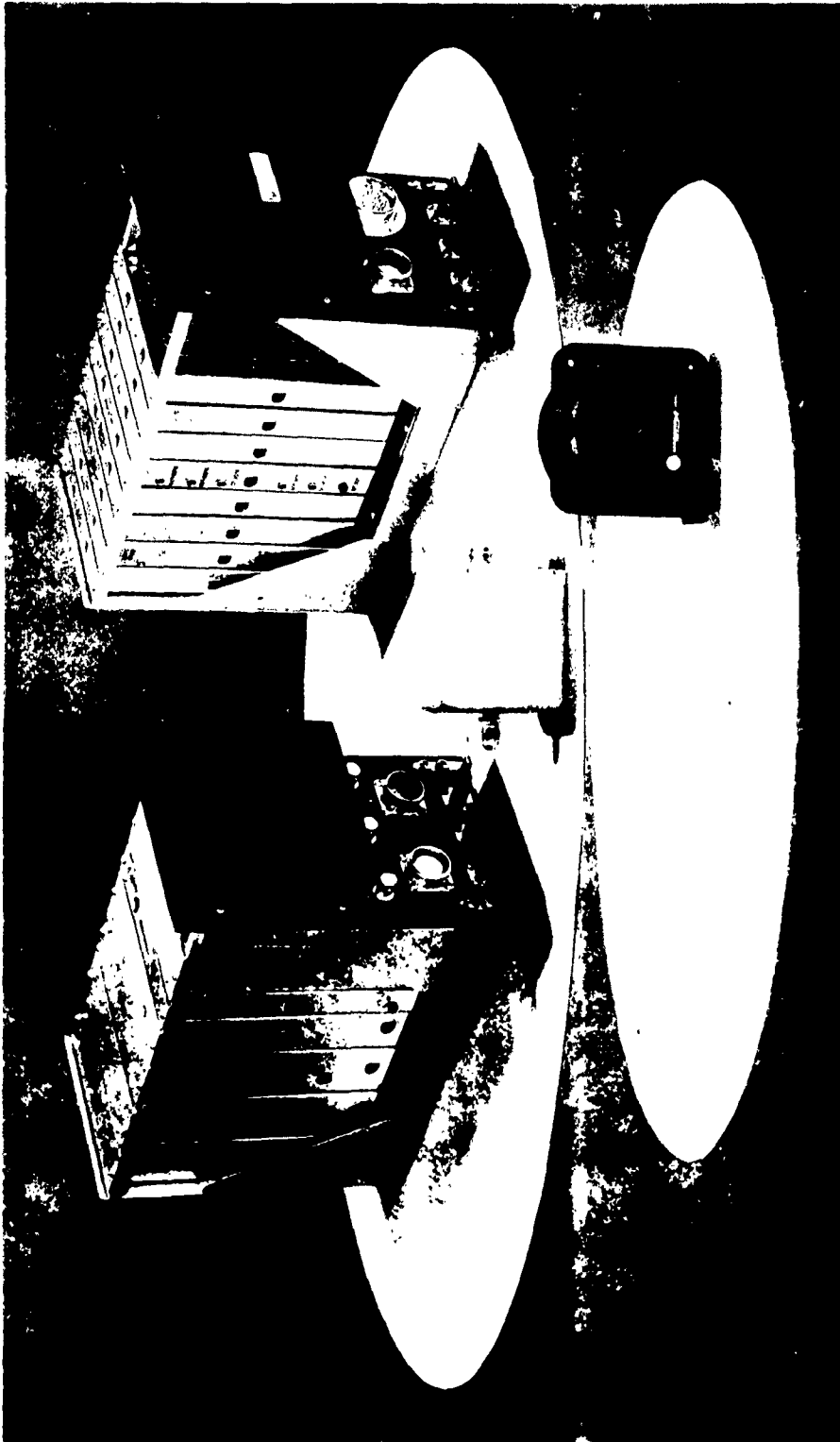


FIGURE 1- PRINCIPAL COMPONENTS OF PWI SYSTEM

Abstract

test. Complete schematics and critical waveforms are included. Recommendations for improvement include increase of channel width to improve range resolution and further development of altitude transducers to improve accuracy. Also, the display utilized is not capable of presenting target range and bearing with accuracy derived by the Receiver-Transmitter.

2. RECEIVER-TRANSMITTER UNIT

Two basic units comprise the Pilot Warning Instrument system. The receiver-transmitter unit performs the function of generating data about the coalitude traffic situation, and the display data processor prepares these data for presentation to the pilot by way of an indicator instrument.

The receiver-transmitter unit is the active portion of the system because it transmits and receives in a programed manner. This unit is comprised of a programer which controls all of the processes in the system; a transmitter which radiates the interrogation and reply signals; three receivers, connected to three antennas, which are capable of determining angle-of-arrival of all replies and the reception of all interrogations; and, finally, a discriminator section where various signal evaluations are made prior to data processing for display.

2.1 THEORY OF OPERATION

To start the system operating, an interrogation pulse must first be transmitted; and to produce a returning signal, there must be a similar system located some distance away to reply. The interrogation pulse occupies the first 300 μ sec of the cycle. Since the recurrence rate of the interrogation is set to nominally 20 cps, the listening and replying time is 49,700 μ sec. Figure 2 is a graphic representation of the basic timing of the program.

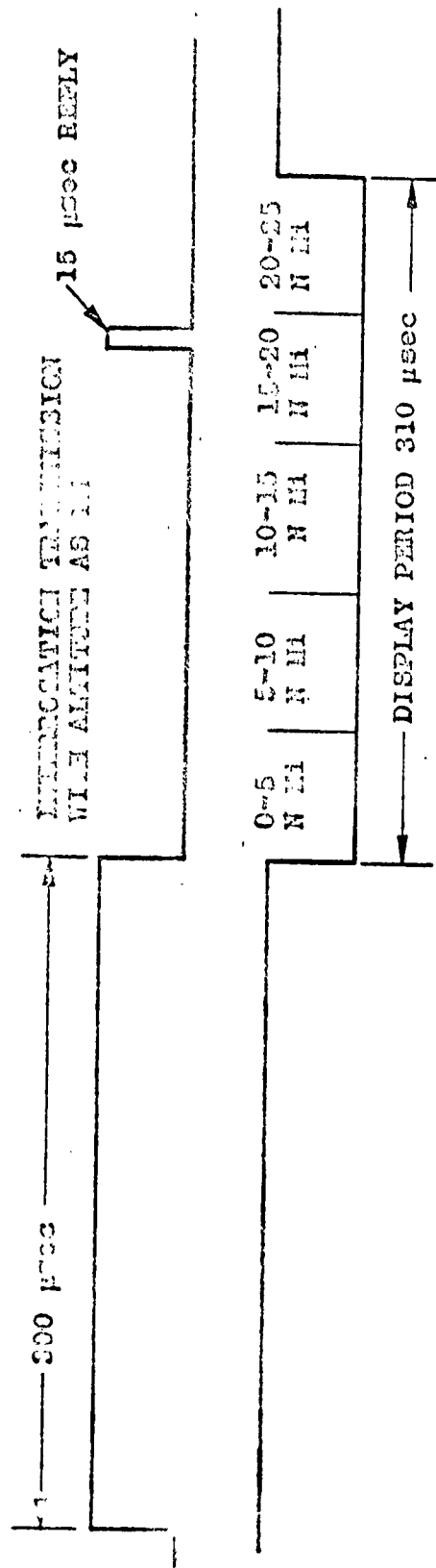
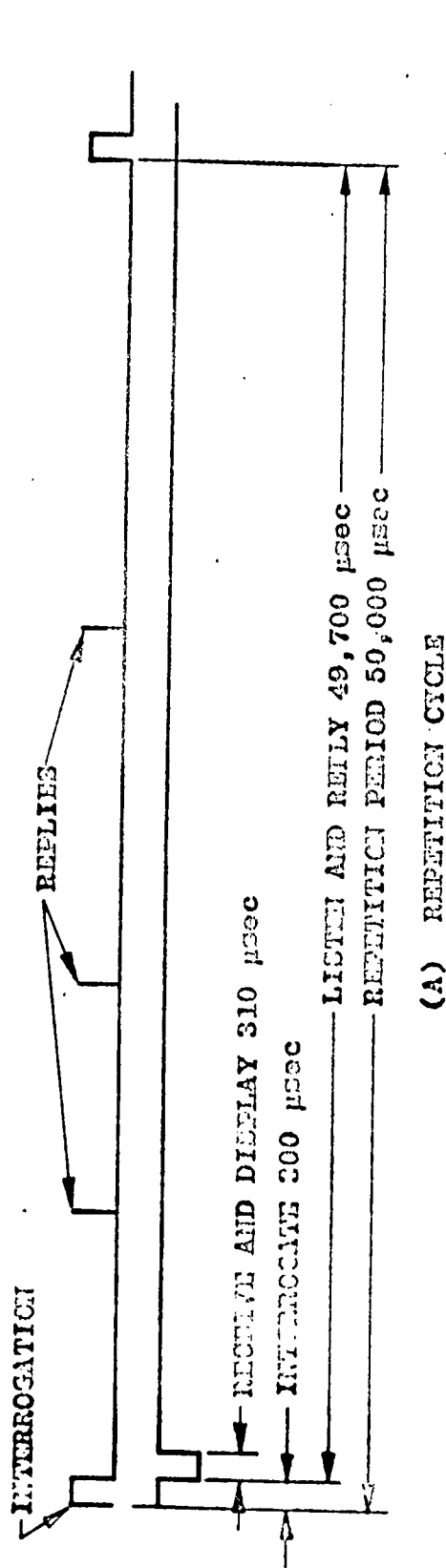


FIGURE 2 - FUNCTIONS AND TIMES

Receiver-Transmitter Unit: Theory of Operation

During the long listening time following the interrogation pulse, each system may respond to external interrogations and reply, as well as receive replies to its own interrogation. Replies of interest to each internal interrogation are displayed in the first 310 μ sec, which represents a maximum range of 25 nautical miles.

Figure 3 is a functional diagram of the receiver-transmitter unit. Altitude coding is in the form of frequency modulation of the pulse carrier during the interrogation pulse time with the modulation frequency being a function of pressure altitude. For a reply to be generated, the replying system must be at nearly the same pressure altitude as the interrogating system. In the reply circuit of each system there is a pressure-operated filter tuned to the same frequency as the oscillator. Both the oscillator-tuned circuit and the filter-tuned circuit are located in one unit, and mechanically operated by sealed bellows connected to the aircraft static pressure line. The energy of the altitude-coding oscillator phase modulates the transmitter during interrogation, and the tuned filter related to the frequency modulation discriminator controls the reply circuit.

At the end of an interrogation pulse from a coalatitude system, the reply section generates a trigger which initiates the transmission of a 15- μ sec reply. This reply transmission

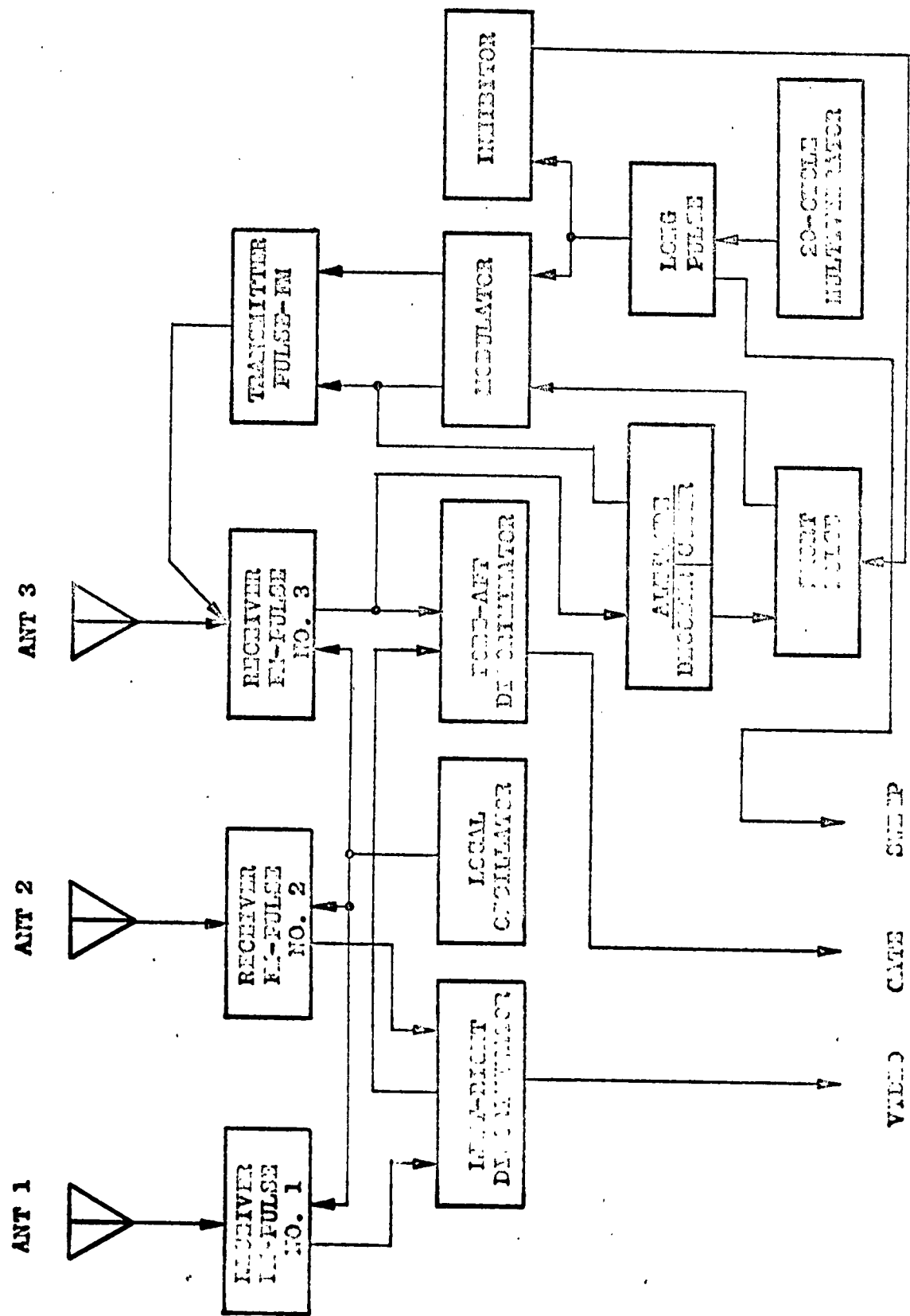


FIGURE 3 - FUNCTIONAL DIAGRAM OF RECEIVER-TRANSMITTER UNIT

Receiver-Transmitter Unit: Theory of Operation

is received by three antennas which are arranged in a triangle so that direction of arrival may be determined. The time delay of the reply from the end of interrogation is the measure of range.

Angle determination is accomplished by measuring the time difference of arrival of an electromagnetic wave front at the three antennas. The geometry of the antennas mounted on the aircraft establish the parameters of the system angle sensitivity.

At the operating frequency of the PWI system the wavelength of the radiated energy is 88 inches. To establish a non-ambiguous electrical phase measurement the antennas must be spaced no greater than one-fourth wavelength. The maximum phase difference that can be measured by the two antennas is determined by their spacing.

With the antennas spaced at about 90 percent of one-fourth wavelength, the data processing in the discriminators is simplified. Maximum phase difference appearing at the antennas is about 70 electrical degrees.

Fore-aft determination is made by placing a third antenna to the rear of the two transverse antennas forming an isosceles triangle, whose base and height are the same. This arrangement will provide approximately the same angular sensitivity for the fore-aft determination as compared to the right-left sensitivity.

Receiver-Transmitter Unit: Theory of Operation

The three identical receivers amplify the signal received at each of the three antennas. The receivers are double conversion, superheterodyne types with a common local oscillator to establish phase identity through all receivers. Each receiver has its own oscillator injection multiplier section with a phase adjustment to permit establishment of overall phase relationship between the receivers.

The two receivers connected to the transverse antennas (designated as Ant 1 and Ant 2) operate into the left-right discriminator, and the receiver connected to Ant 3 operates into the fore-aft discriminator. The quadrature reference is developed from the signals of receivers 1 and 2. The output of the left-right discriminator is a pulse voltage response representing left-right position, and the output from the fore-aft discriminator is a pulse representing a determination that the response is in the forward sector. These output signals are applied to the data processor and, finally, to the display.

The programing unit provides all the required timing and control functions for the operation of the transmitter and display. Generation of the basic recurrence rate of the system is accomplished by a 20-cycle multivibrator whose frequency is self-determined and, by design, is none too stable in frequency. This instability prevents the systems from

Receiver-Transmitter Unit: Theory of Operation

locking-on each other, and running in synchronism. A 300- μ sec multivibrator, which is triggered by the 20-cycle multivibrator, produces the interrogation pulses for the transmitter and phase modulator. Also, the trailing edge of this pulse starts the range sweep in the data processor unit. During the interrogation pulse, the phase modulator is gated on, to enable transmission of the altitude code signal.

At the end of interrogation, an inhibitor multivibrator is triggered to generate a short pulse, which is applied to an inhibitor gate to prevent the system from replying to itself. At the end of this inhibition, the system is in the listening mode.

2.2 RECEIVING SECTION

The receiving section of the proximity warning equipment consists of three transistorized receivers of the double conversion superheterodyne type. In principle, these receivers are similar to the receivers extensively employed in the land-mobile service with the exception that the design of the second IF amplifier has been specifically adapted to the stringent phase stability requirements of the instantaneous direction finding system.

Refer to Figure 4, Receiver Block Diagram, for the following discussion.

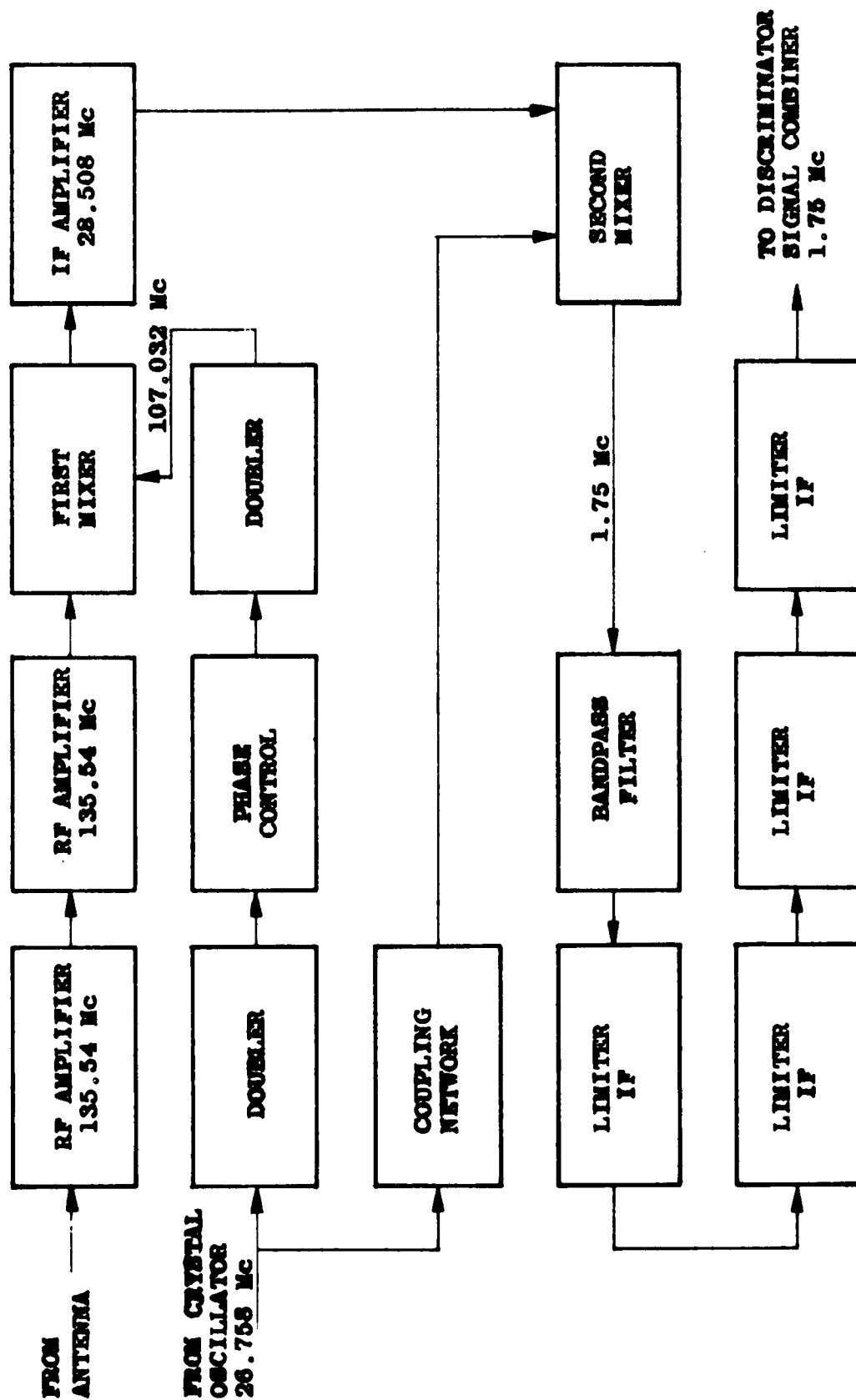


FIGURE 4 - RECEIVER BLOCK DIAGRAM

Receiver-Transmitter Unit: Receiving Section

The Pilot Warning Instrument receiver obtains its signal from a 50-ohm coaxial transmission line, which is matched into its appropriate antenna at a frequency of 135.54 Mc. This input signal is fed through a series resonant circuit to the emitter of the first of two ground-base rf amplifiers operating at signal frequency. These amplifiers feed the first mixer of the superheterodyne system. Local oscillator injection is obtained from an external crystal oscillator source at a frequency of 26.758 Mc. This local oscillator signal frequency is multiplied four times through two transistorized doubler stages and the resulting local oscillator signal is fed to the mixer at the frequency of 107.032 Mc. The output of the mixer, which is the difference frequency between signal frequency and mixer injection frequency, is at a frequency of 28.508 Mc. This first IF signal is amplified in a two-stage transistorized amplifier and the output of this amplifier is applied to the base of the second mixer; in this case a transistor rather than a diode as in the first mixer.

The external local oscillator source is applied at the basic frequency of 26.758 Mc to the emitter of this second mixer through a bandpass filter which provides isolation of sufficient magnitude to prevent any modulation of the crystal oscillator source by the difference frequency current

Receiver-Transmitter Unit: Receiving Section

in the output of this second mixer. This final difference frequency is centered at a frequency of 1.75 Mc. The output of the second mixer feeds a modified Permakay filter having a 300-kc bandpass centered at the center output frequency of 1.75 Mc. This filter is the basic selectivity control of the receiving system and provides sharp attenuation of frequencies lying outside its passband of 1600 to 1900 kc.

The second IF amplifier is of a special design which is employed to insure phase stability of the amplifier for varying signal levels. In its simplest term each amplifier stage consists of an input signal limiter and a transistor. This input signal limiter has been constructed such that almost irrespective of the magnitude of this input voltage, the voltage applied to the base of the transistor amplifier will be limited to a value of between 50 and 100 mv. In this way the transistor amplifier always operates at constant gain and the attenuation of the input limiter is a function of signal level. At very low signal levels the attenuation of the limiter is negligible; at high signal levels it can readily exceed 20 db, which is more than the gain of the first stage of the transistor. The final transistor amplifier operates into an output limiter which limits the output voltage of the receiver at a level of approximately 2-1/2 volts rms. This level is set through the proper combination of an rf-diode and Zener-diode.

Receiver-Transmitter Unit: Receiving Section

One of the requirements of the directional and range display unit is that the receiver connected to the aft antenna provide an amplitude modulated detector output. This output is obtained by diode means at the collector circuit of the second of the 1.75 Mc amplifier stages. An additional feature that should be noted is the use of a diode at the midpoint of the input series resonant circuit which feeds the first radio frequency amplifier. This diode limits the voltage applied to the receiver when the associated transmitter is keyed either for interrogation or for reply.

2.3 DISCRIMINATORS

The discriminators and signal combiner unit complete the receiving section of the PWI system. IF output from each of the receivers is combined and demodulated to produce the required signals for further processing and display.

Figure 5 is the schematic of the PWI discriminator.

Output from receivers 1 and 2 are combined in the azimuth discriminator transformer so that the phase difference appears in the secondary and the sum appears at the center tap of the primary. The sum is used as the phase discriminator reference after being shifted 90° electrically. This reference is also used in the fore-aft discriminator whose input comes from receiver 3. These discriminators are balanced to ground and their output signals are symmetrical about zero voltage.

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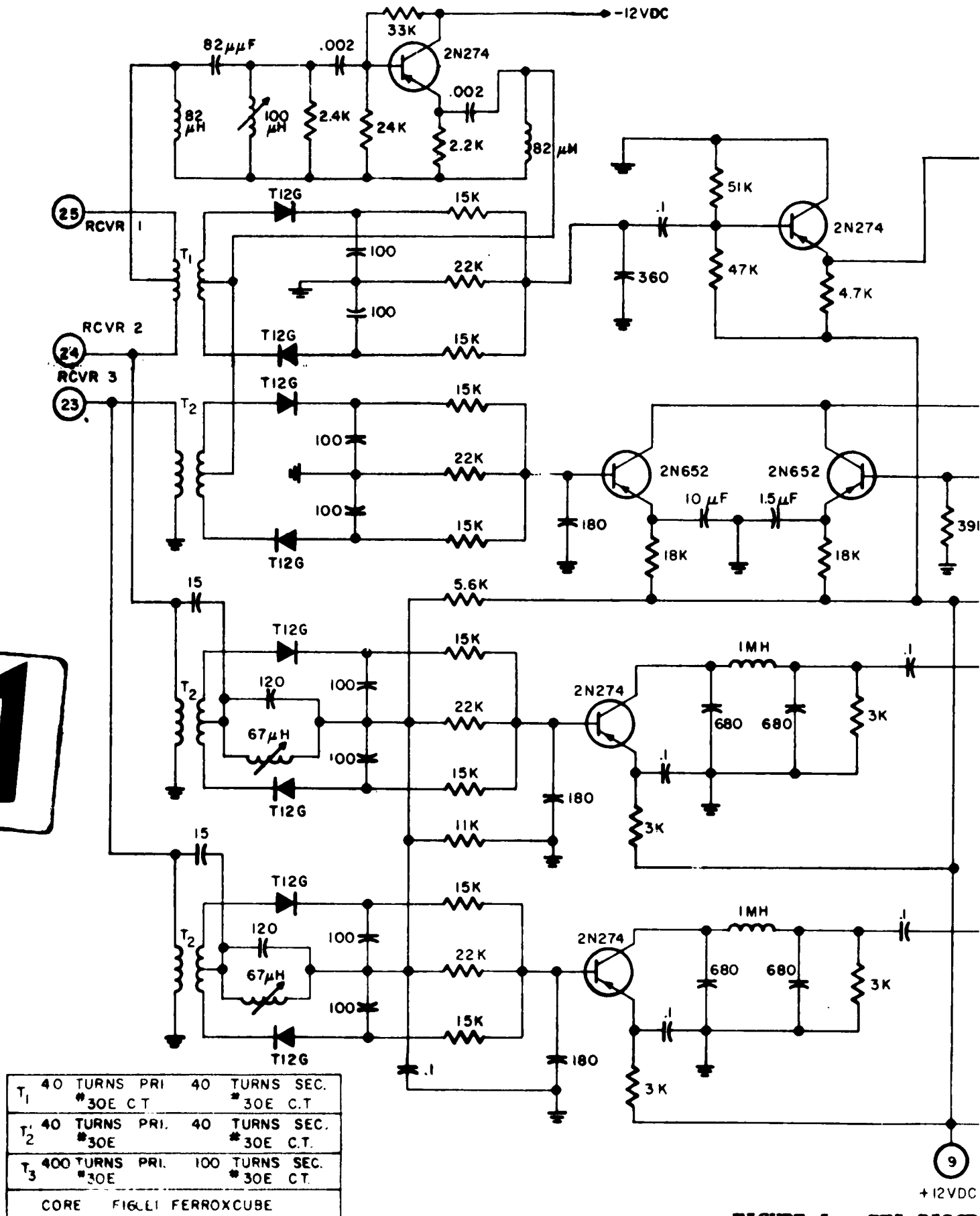


FIGURE 5 - PWI DISCR

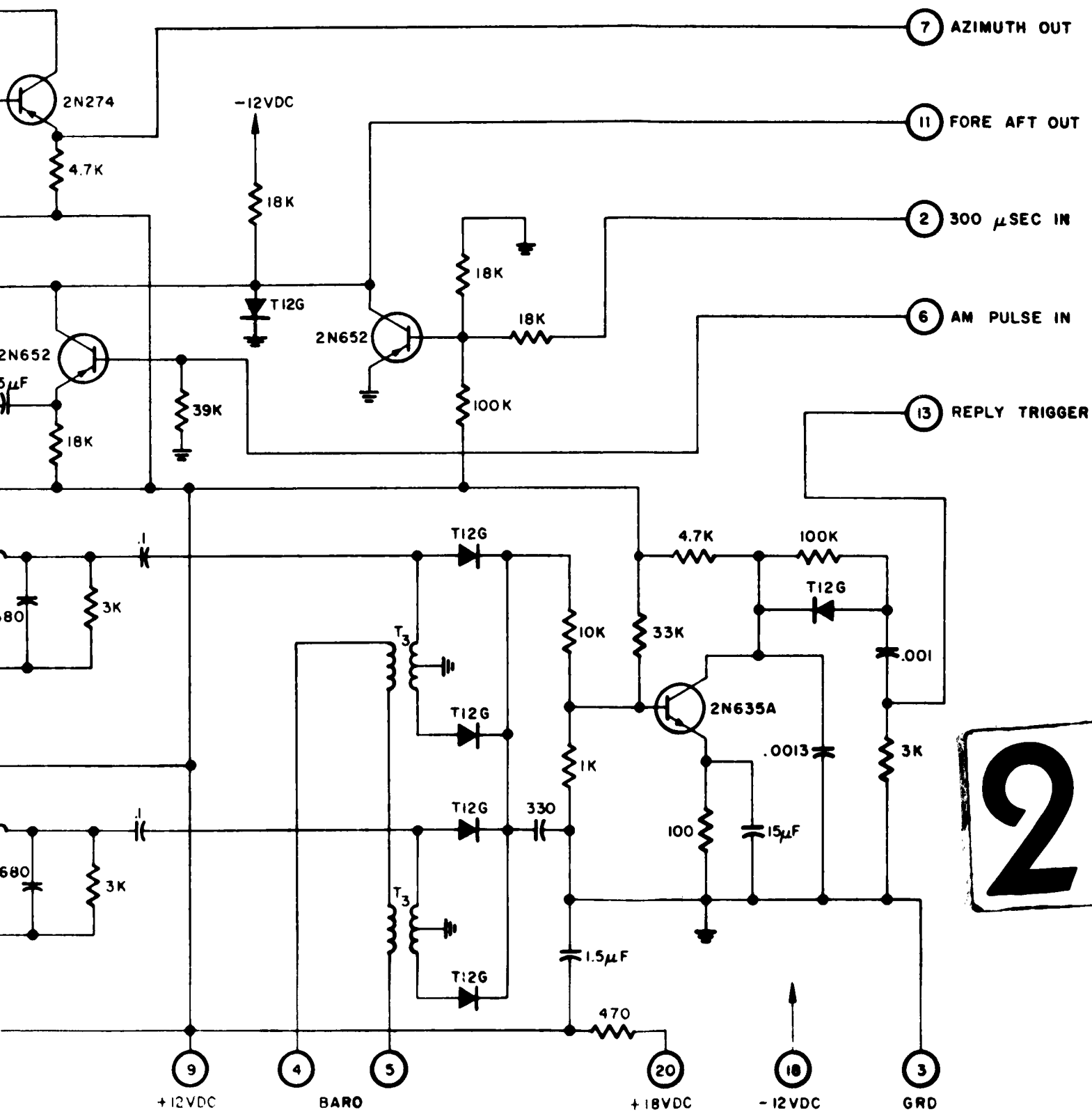


FIGURE 5 - PWI DISCRIMINATOR

Receiver-Transmitter: Discriminators

The azimuth discriminator output is connected to an emitter follower which then feeds this video signal to the display logic unit.

The discriminator that recovers the fore-aft pulse is connected to one of two transistors forming a small signal AND gate. The second signal applied to the second leg of this AND gate is developed in receiver 3 as a positive AM pulse. Both transistors in this AND gate are turned on so that a small positive pulse will produce a negative pulse at the output; however, both the fore-aft and the AM detected pulse must occur simultaneously.

Two pulses are required in producing the fore-aft output pulse to reduce the probability of false alarm. The 300- μ sec pulse is also introduced into a third transistor so that no signal can appear at the fore-aft output during interrogation. This circuit eliminates the local interrogation pulse from causing possible disturbance in the data processing unit which would result in false indication.

The reply trigger pulse is generated at the end of the interrogation pulse which is frequency modulated with an altitude code. Two fm discriminators operating from two separate receivers recover the altitude code signal and apply it to the decode circuit. This decoder is the barometer

Receiver-Transmitter Unit: Discriminators

controlled series resonance circuit which is connected to the reply pulse circuit through the windings in the two noise transformers.

If an interrogation pulse carries the same frequency modulation as the decoder tuning, then the noise transformers are essentially short circuited through the secondary winding on each transformer. Thus during the interrogation pulse the noise rectifiers have no signal. At the end of the interrogation pulse the receivers will produce noise which is rectified and causes a pulse to be generated.

When an interrogation pulse occurs carrying a frequency different from the decoder tuning, the noise diodes will have this signal to rectify. At the end of the interrogation pulse the receiver noise reappears causing the diodes to produce about the same rectified voltage. As a result, no reply pulse can be generated in the reply circuits.

2.4 PROGRAMMER

The programmer provides all the required control functions for the transmission of interrogation and reply pulses, and controls the timing of the display data processor. Figure 6 shows the principal programmer elements and their relationships.

Establishment of the basic recurrence rate of the PWI system is accomplished by the 20-cycle multivibrator. This transistorized, astable multivibrator has a frequency that is

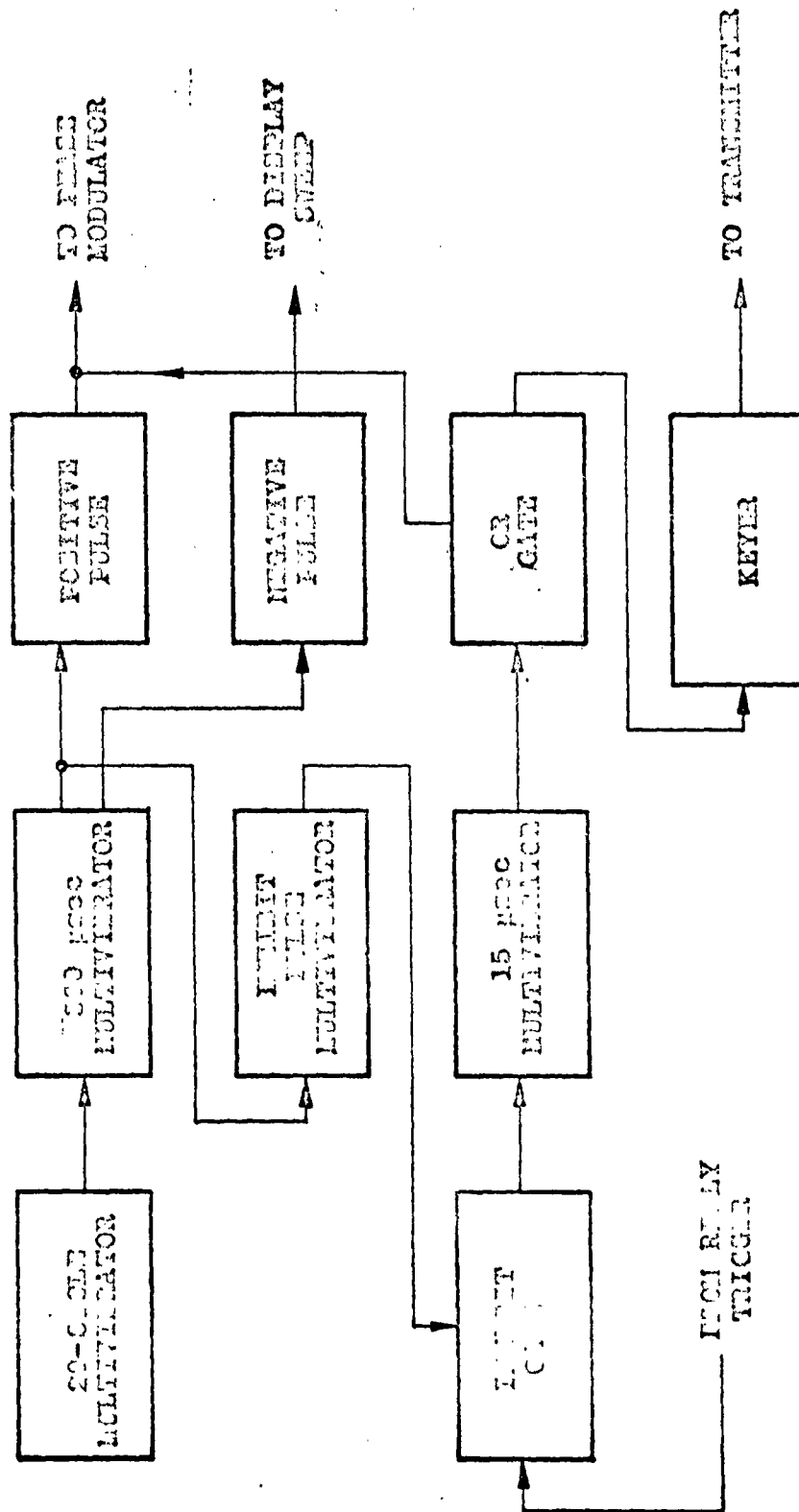


FIGURE 6 - FUNCTION DIAGRAM OF PPI PROGRAMMER

Receiver-Transmitter Unit: Programmer

determined within itself and is isolated from trigger influence of the associated circuits. As a result, the triggering of the interrogation pulse is independent of all signal influence which might cause synchronization with other PWI systems.

The 300- μ sec multivibrator generates the interrogation pulse applied to the transmitter through an OR gate and the transmitter keyer. This is a positive pulse of 12 volts amplitude and turns on the keyed amplifier stage in the transmitter by overcoming the large bias voltage of this stage. The negative polarity, 300- μ sec pulse is applied to the display data processor to establish the range timing sequence in that unit.

This same 300- μ sec pulse is applied to the phase modulator to enable transmission of the altitude code modulation during interrogation.

To prevent the system from replying to its own interrogation, a short inhibit pulse is generated at the end of the interrogation pulse and is applied to an inhibit gate. This prevents the reply trigger, which is generated in the discriminator section, from operating the 15- μ sec multivibrator. The inhibit pulse length is made sufficiently long to allow the self-reply trigger to occur, but after this delay any reply trigger can operate the 15- μ sec multivibrator.

Receiver-Transmitter Unit: Programer

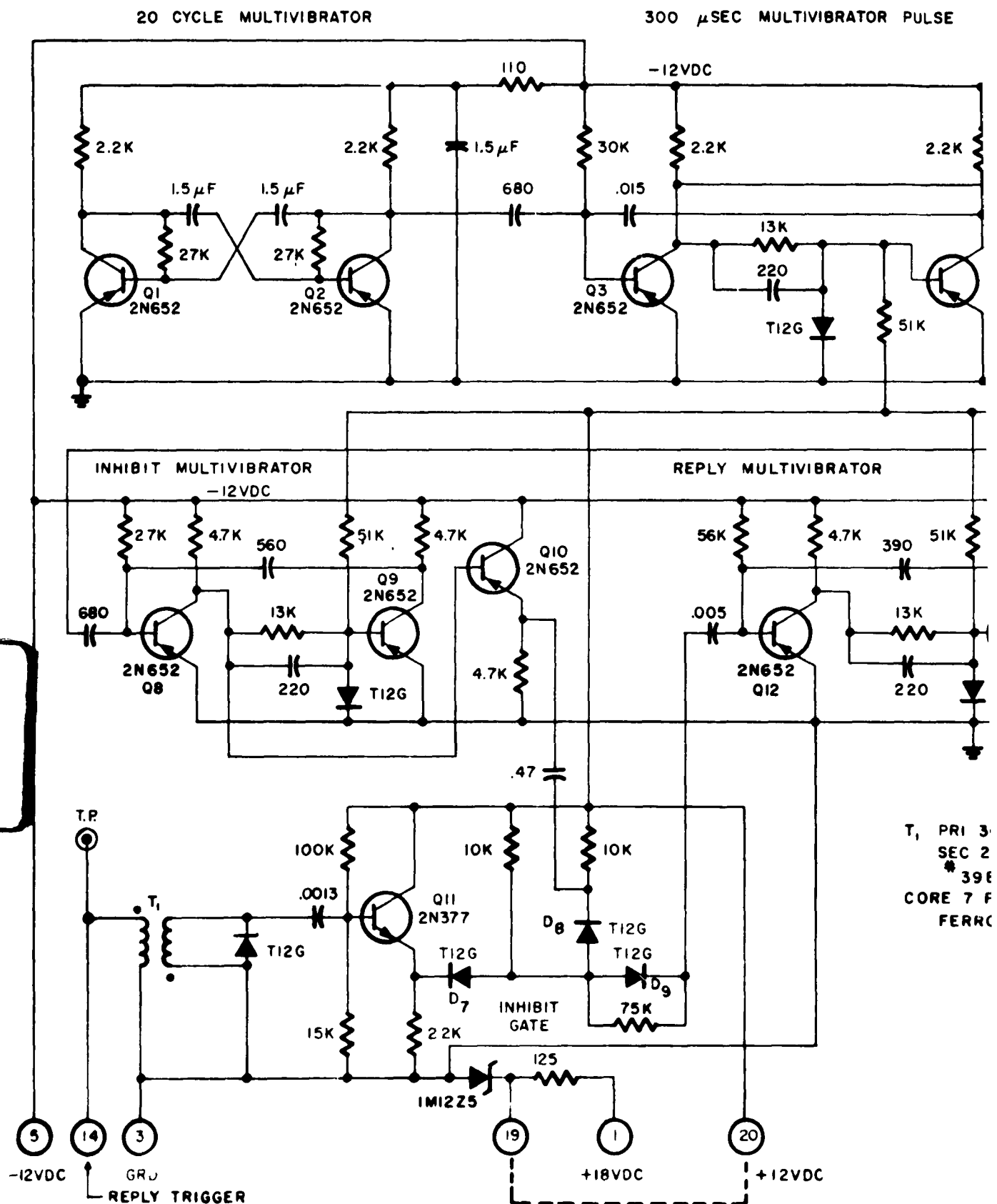
The output of the 15- μ sec multivibrator is applied to the transmitter keyer through the second leg of the OR gate and the transmitter keyer. This pulse voltage is the same as that of the 300- μ sec pulse.

Most of the circuits shown in Figure 7, are standard multivibrators and amplifiers arranged to operate as described above. However, the operation of the circuits which are not readily apparent are described below.

The inhibit gate circuit operation is a combination of diodes forming an AND gate but biased in a manner to produce no signal output in the presence of two signal inputs. An emitter follower Q11 provides a low impedance source positive reply pulse from the discriminator to drive the diode D7. The emitter follower Q10 drives the diode D8, with the inhibit pulse, and the output of this gate is at the junction of the two diodes.

Diode D7 is biased on through the 10,000 ohm resistor, permitting signals to pass through. At the same time, diode D8 is biased off through the 10,000 ohm resistor. When the inhibit multivibrator generates a negative pulse, diode D8 conducts causing the potential of the junction of these two diodes to drop to zero turning off diode D7. This prevents any signal from emitter follower Q11 from passing through the gate. This negative inhibiting pulse can trigger

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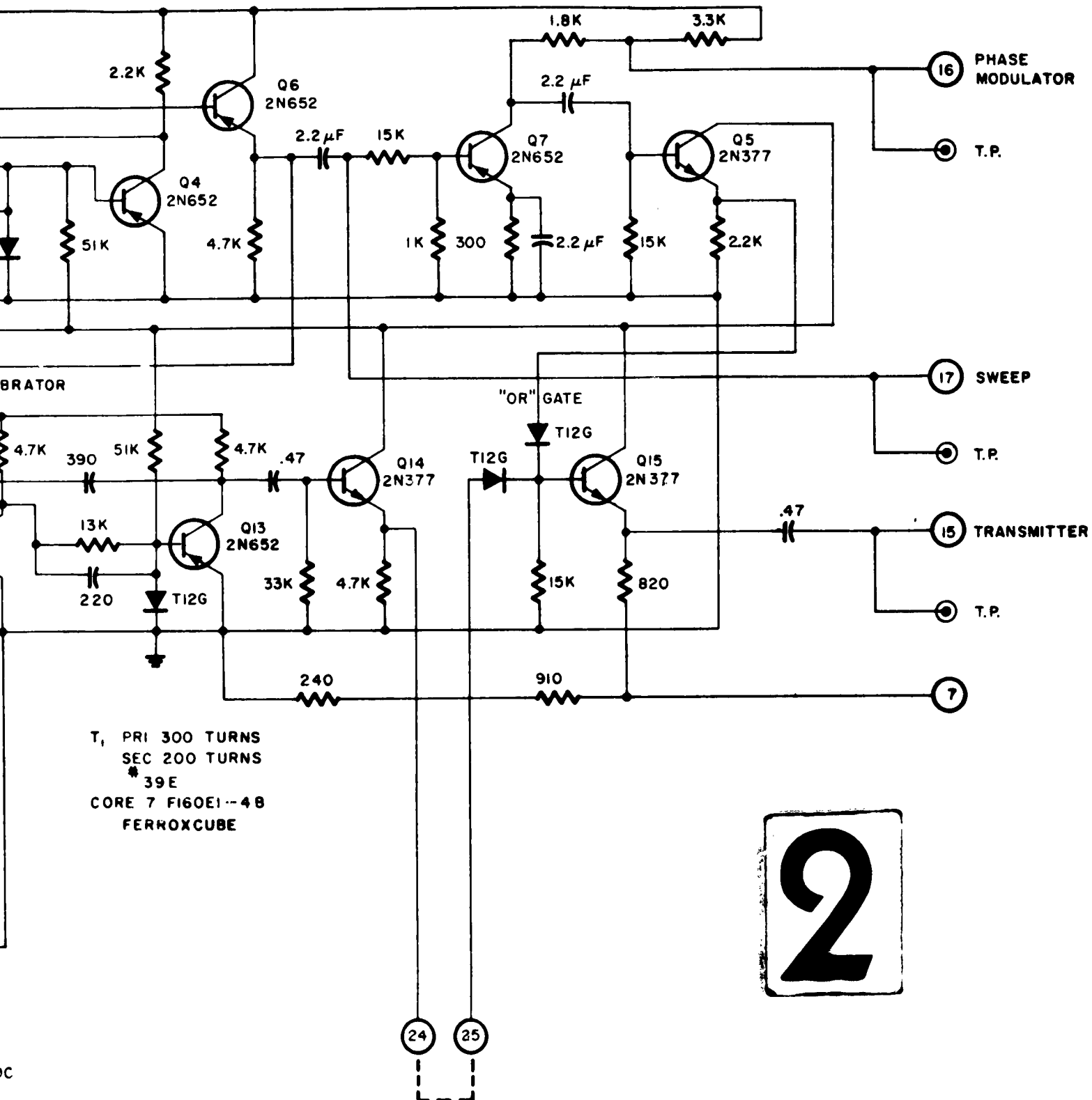


T₁ PRI 3
SEC 2
39E
CORE 7 F
FERRC

FIGURE 7 - SCHEMATIC

VIBRATOR PULSE

ALTITUDE MODULATOR KEYS



2

FIGURE 7 - SCHEMATIC PWI PROGRAMMER

Receiver-Transmitter Unit: Programer

the 15- μ sec multivibrator at the trailing edge due to differentiation in the coupling circuit. A diode shunted with a resistor can prevent differentiation of the inhibit pulse and still pass the required positive pulse from emitter follower Q11.

A negative pulse cannot pass through diode D9 leaving only the long time constant resistance path for this pulse. On the other hand the required positive pulse can pass through the diode without loss and cause proper triggering of the 15- μ sec multivibrator.

The OR gate at the input of the transmitter keyer Q15 accepts positive pulses from either the 15- μ sec multivibrator or the 300- μ sec multivibrator. Diodes D4 and D5 are biased so that neither pulse source will interfere with the other.

2.5 TRANSMITTER

The transmitter is a keyed fm-cw type using a crystal oscillator for frequency control followed by a phase modulator and two frequency doublers.

It is essential that the transmitter be extremely quiet during the listening period of the system and be able to produce good pulse output when it is keyed on. These paradoxical requirements required special precaution to be taken in the design considerations of this unit.

Receiver-Transmitter Unit

The crystal oscillator is a transistorized Pierce circuit where the crystal itself is the tuned circuit. This circuit is arranged so that the output lead is also the power input lead. With this arrangement the leakage energy radiating from the oscillator can be held to an absolute minimum with good shielding. In addition to the single lead integrity, a four-section, tuned, lowpass filter that is separately shielded from the oscillator prevents any harmonic distortion appearing in the circuits external to the oscillator. With this lowpass filtering the oscillator may be in continuous operation without creating interference in the receivers. Figure 8 shows the oscillator and filter schematic.

RF energy from the filter is amplified by a Nuvistor tetrode operating in class C. An additional tetrode is employed as a phase modulator where the altitude coding is introduced to the transmitter. Both of these tubes operate into a single tuned circuit at the crystal frequency. The bias conditions on these tubes is established to cut off the cathode current completely. This is necessary to keep the transmitter absolutely quiet during the listening period of the system operation.

The phase modulator and the amplifier are keyed separately from the programmer in order that altitude modulation may be transmitted only during interrogation. This means that the phase modulator tube is grid-keyed only during the 300- μ sec

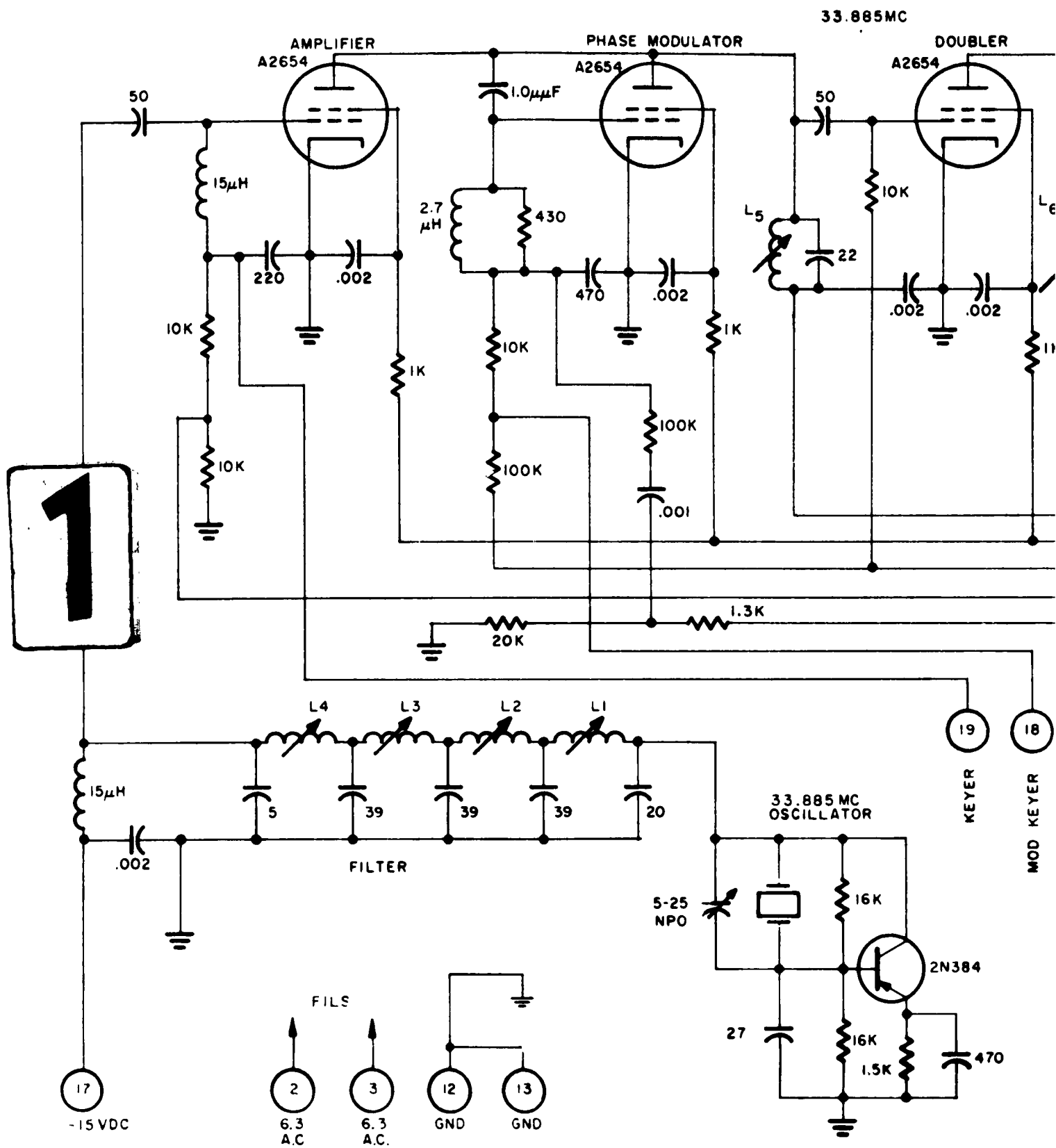


FIGURE 8 - SCHEMATIC PWI



Receiver-Transmitter Unit: Transmitter

interrogation. The amplifier tube is grid-keyed during the 300- μ sec interrogation and during all the 15- μ sec reply pulses.

The amplifier-phase modulator stage is followed by a Nuvistor doubler stage with fixed bias to establish class C operation. The doubler tube cathode current is cut off during the quiet time of the transmitter. This stage provides amplification as well as a multiplication in frequency. A second Nuvistor doubler stage follows and the operating conditions are the same as for the first doubler. The exception is the nature of the tuned output circuit.

A bifilar coil forms the coupling circuit from the second doubler to push-pull grids of the output power amplifier stage. This tuned circuit is slug-tuned as are all preceding tuned circuits. The output stage makes use of two subminiature, beam-power tetrodes operating into a split stator tuned output circuit which is symmetrically coupled into an antenna coil.

Part of the antenna duplexing network is included in the transmitter unit. This network consists of a quarter wavelength feed from the transmitter to the junction point of the receiver antenna terminal and the lead to the antenna jack. Part of the required length of feed is a coil of miniature 50-ohm cable connecting the antenna coil to the terminal at the base of the transmitter unit.

Receiver-Transmitter Unit

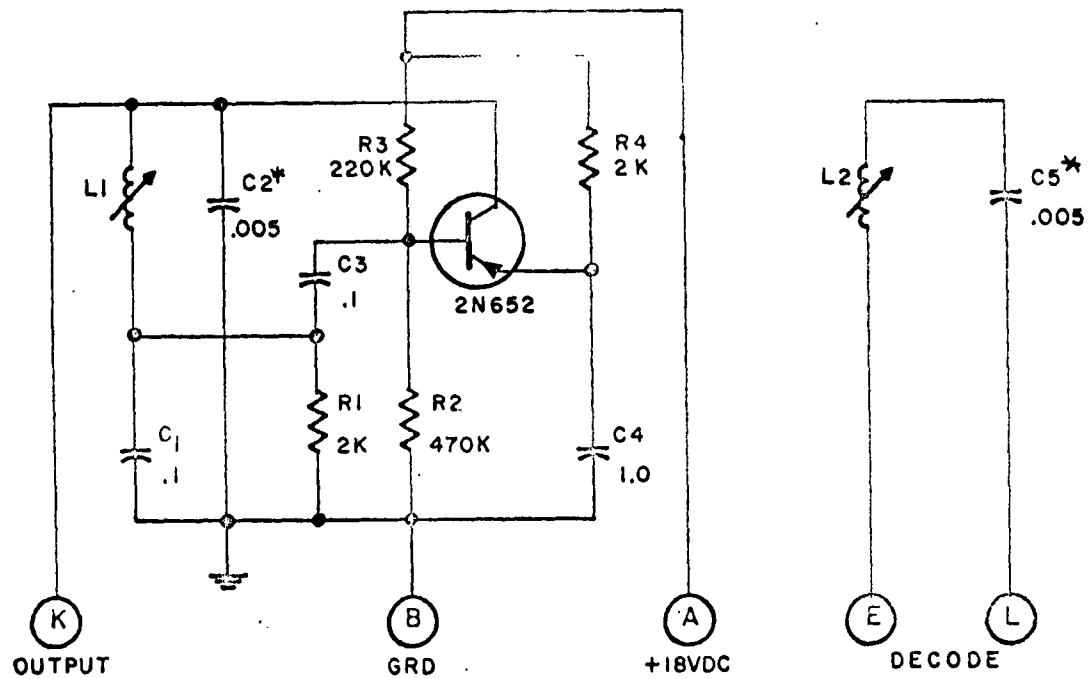
2.6 BAROMETER ENCODER-DECODER

Altitude data are introduced into the system as a frequency modulation during the interrogation pulse, and this frequency is decoded for generation of a reply pulse. Figure 9 shows the schematic of the barometer coder-decoder unit. The oscillator portion is a transistorized Colpitts circuit whose frequency is controlled by a variable inductance. An identical variable inductance forms part of the series resonant decoder.

Variable inductances are wound on ferrite cup core assemblies with the cup and coil portion mounted to the frame of the barometer unit. The cap portion of the ferrite core is mounted to the barometer bellows to provide the variable air gap in the magnetic circuit. Variation of this gap causes a change in the inductance of the coil as a function of altitude. This variation in inductance determines the frequency of the oscillator and the series resonance decoder.

The oscillator output is applied to the phase modulator of the transmitter to produce the required frequency modulation during transmission of the interrogation pulse. The series resonance decoder is part of the reply demodulator decoder which determines when the interrogation is in the altitude layer of the decoder.

This portion of the system has several variables which control the altitude sensitivity. The amount of frequency



* APPROXIMATE VALUES MADE UP OF SILVER
MICA CAPACITORS TO ACHIEVE TRACKING
OF ALL FREQUENCIES

L_1 AND L_2 COILS WOUND ON FERRITE CORES WITH
AIR GAPS CONTROLLED BY BAROMETER BELLOWS

FIGURE 9 - BAROMETER CODER-DECODER

Receiver-Transmitter Unit: Barometer Encoder-Decoder

deviation has the greatest effect on the altitude sensitivity. The tuning of the phase modulator and the phase modulator tube itself are variables as well as the applied signal voltage from the barometer controlled oscillator. The other significant variable is the tuning of the frequency modulation discriminators in the reply generation circuits.

2.7 POWER SUPPLY

A transistorized dc-to-dc converter is used to change the positive 27.5 volts dc from the aircraft supply to the required voltages for the operation of the receiver-transmitter unit. The converter is essentially a switch, a transformer, and a rectifier.

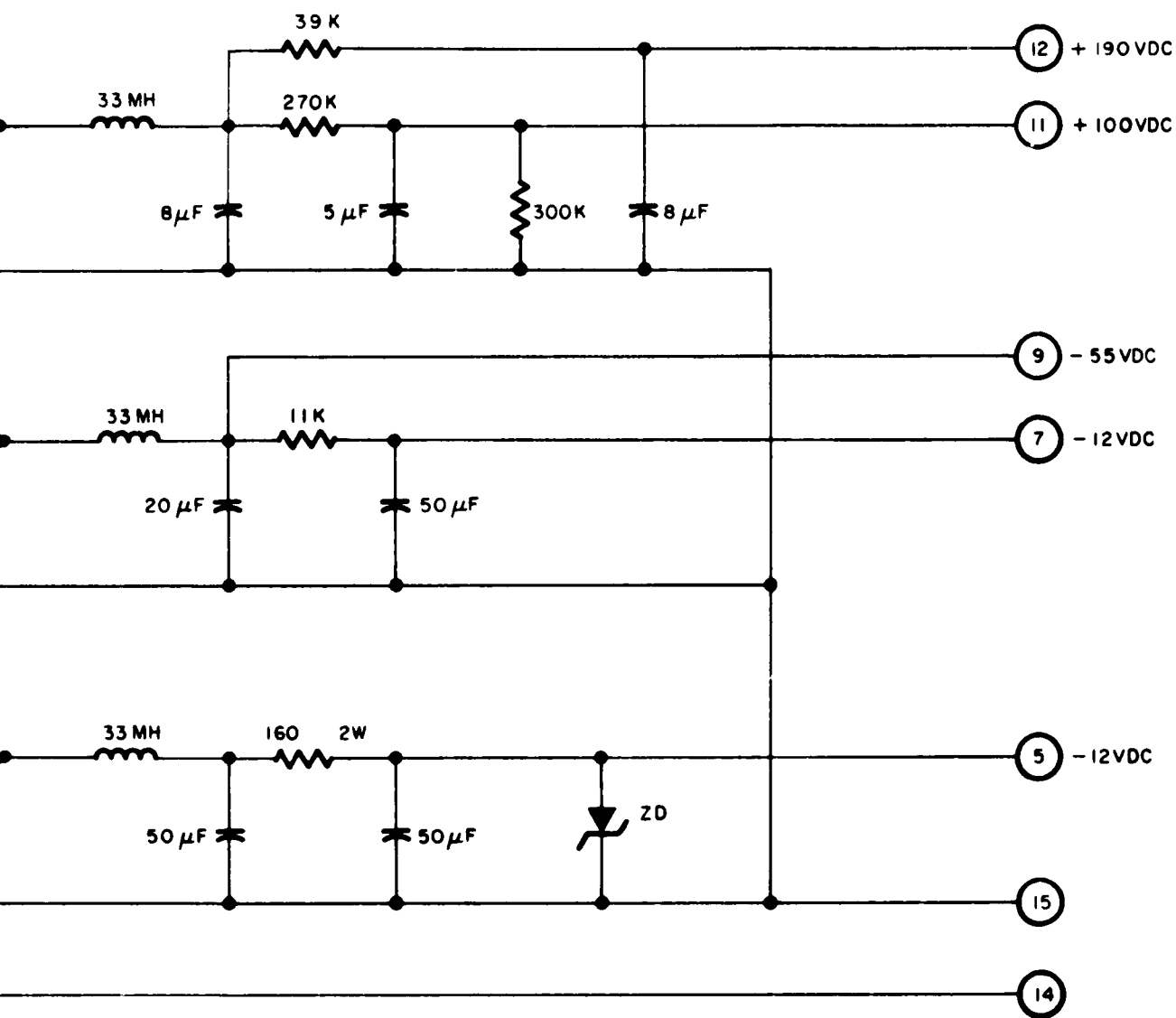
A transistor multivibrator, whose free running period is established at approximately 2000 cps by a saturable core transformer, acts as the switch. The low ohmic drop across a transistor in the full ON condition, combined with its capability of rapid switching, makes it an ideal element for use in a dc-to-dc converter. The voltage drop in the ON transistor is negligible compared with the dc supply voltage, so that the supply voltage appears across one-half the primary of the transformer for one-half cycle of the oscillator. The polarity of the feedback winding holds one transistor in the ON state; the other in the OFF state. When the transformer core saturates, the induced voltage in the feedback

Receiver-Transmitter Unit: Power Supply

winding falls to zero, which reduces the feedback to zero. The transistor that was originally cut off starts to conduct, reversing the direction of the flux which induces a voltage of opposite polarity in the transformer. This voltage reverses the state of the transistors.

The square wave generated across the primary of the transformer appears in the secondary windings. Several secondary windings are used to provide the various required voltages. The dc voltages are produced by bridge rectification and stabilized by Zener diodes. One winding supplies heater power to the transmitter tube filaments. Figure 10 shows the schematic of the receiver-transmitter power supply.

The power supply is constructed to mount on the upper portion of the front panel of the receiver-transmitter unit with electrical connections being made through a connector located on the power supply mounting base.



NOTES: ZD : 12V ZENER DIODE
 Q₁ AND Q₂ : 2N539 M-H TRANSISTOR

2

MITTER POWER SUPPLY SCHEMATIC

3. DISPLAY DATA PROCESSOR

The display unit for the Pilot Warning Instrument system consists of 30 lights arranged in a semicircular pattern to indicate sectors of range and angle as shown in Figure 11. Range up to 25 miles is indicated by 5-mile concentric sectors while 180° of azimuth, in the forward direction, is indicated by dividing the range sectors into 6 angular sectors of 30° . An illuminated sector indicates the presence of an aircraft within a 5-mile range and a 30° azimuth sector. Only aircraft within the altitude layer of concern are displayed. Multiple aircraft are indicated by more than one light being lit unless they are in the same area.

Such a display presents the pilot with simple, instant, and easy to read information with regard to the relative position of an intruding aircraft.

The physical size of the display unit is the same as that of a standard aircraft instrument and can be conveniently mounted where desired on the instrument panel. The logic circuitry required to illuminate the proper indicator light is contained in a standard 1/4 ATR chassis and weighs approximately 7 pounds. The logic circuitry is transistorized and built on plug-in cards which can be easily removed. Troubleshooting is conveniently accomplished by means of plug-in type jumper cards which make the active cards accessible.

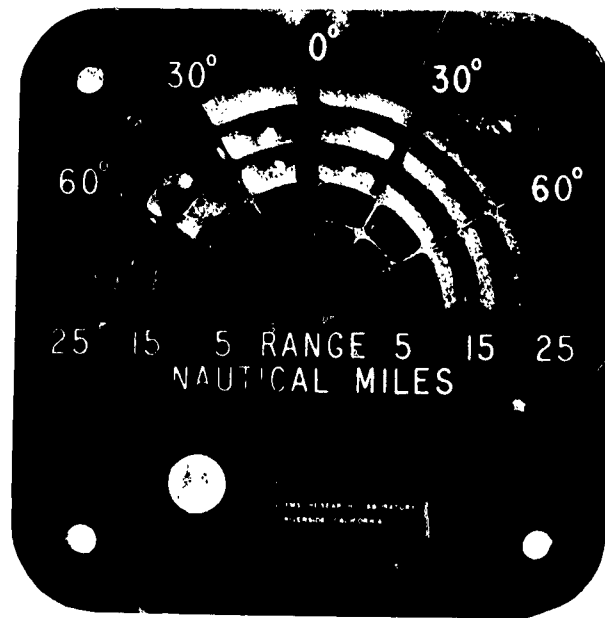


FIGURE 11 - PWI DISPLAY INSTRUMENT

Display Data Processor

3.1 THEORY OF OPERATION

The PWI display function diagram (Fig. 12) shows a digital type of system which causes the proper indicator light to be turned on according to the information presented by the left-right video, fore-aft, and transmitter keying pulse of the PWI system.

The transmitter keying pulse is a negative pulse which is used in the display unit as a time reference for range. The fore-aft pulse is a negative or positive pulse, above noise in amplitude, which indicates whether the received information is from the forward or rear section. A negative fore-aft pulse indicates the received information is from the forward section. The time of arrival of the fore-aft pulse indicates range. The left-right video pulse indicates the angular position of an aircraft by its polarity and amplitude. It occurs as a dc level along a noise train; its time of occurrence also indicates range.

Thirty AND gates are used in the logic circuitry of the display system. Each of these AND gates has two inputs which represent a range and an angular increment. When coincidence exists between these two inputs, an output from the AND gate results and triggers an indicator light multivibrator which turns on the proper light. The multivibrator has a period of 20-msec to obtain a duty cycle sufficient to light the lamp.

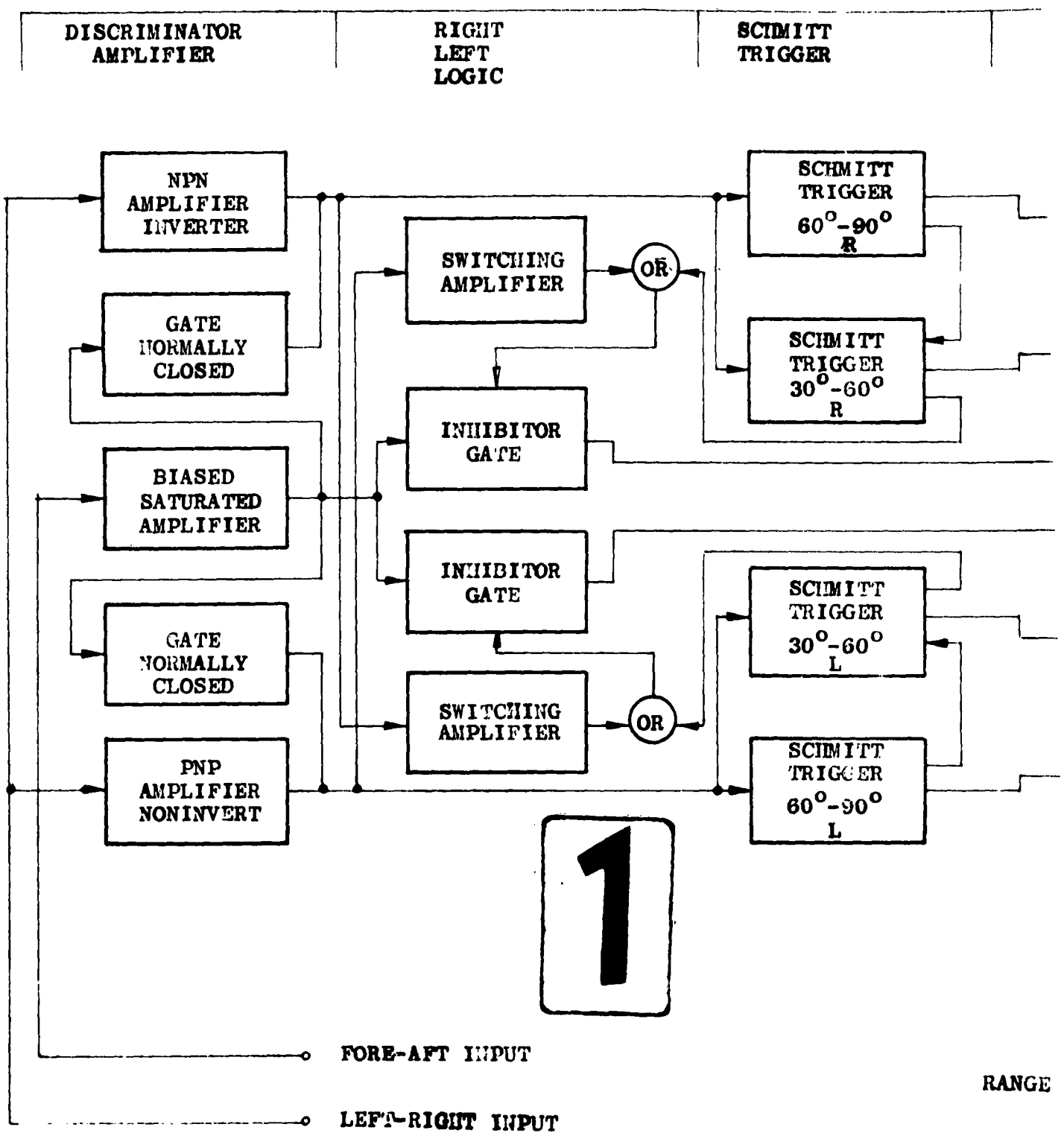
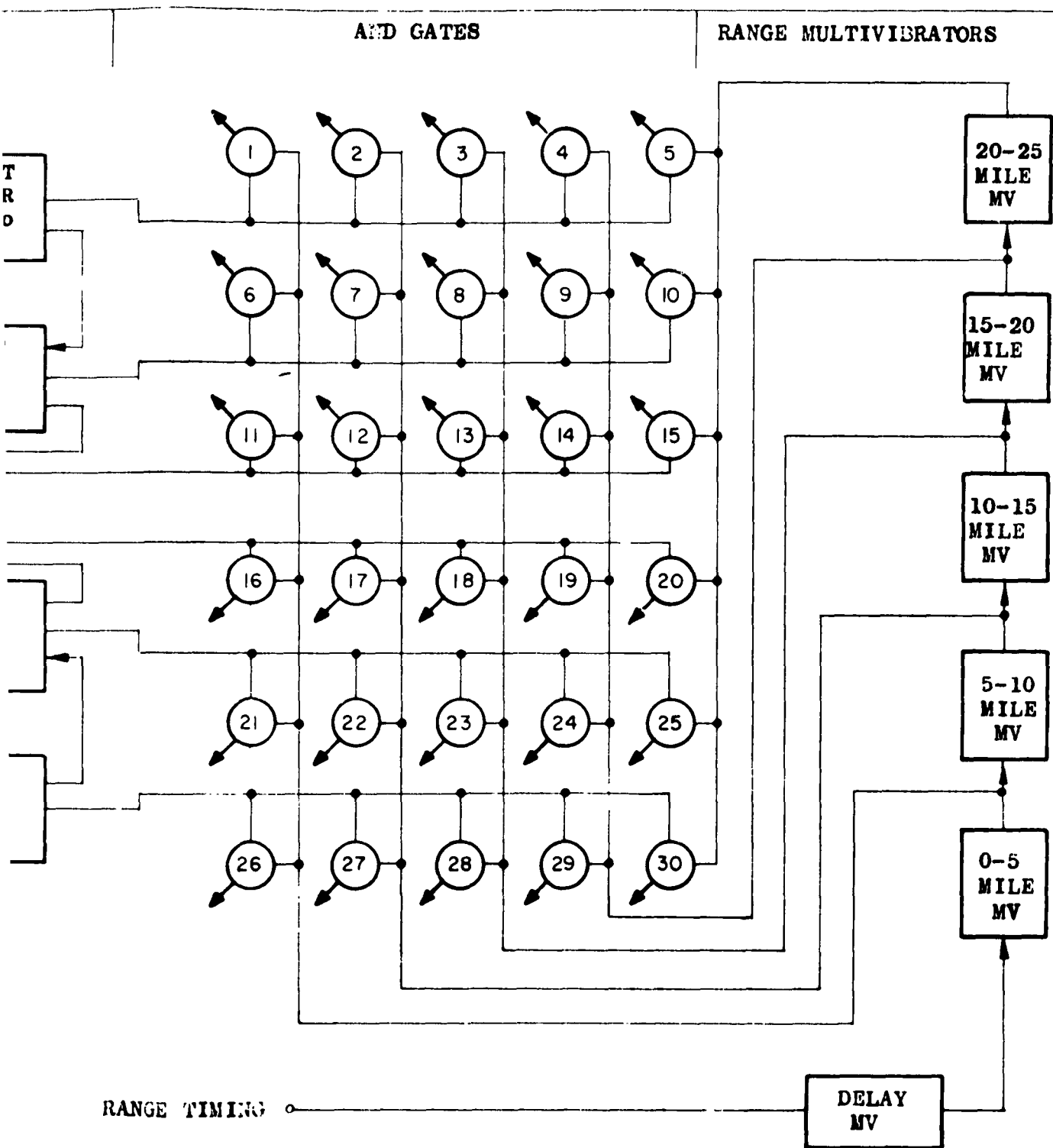


FIGURE 12 - PWI DISPLAY FUNCTION



2

VI DISPLAY FUNCTION DIAGRAM

Display Data Processor: Theory of Operation

The azimuth angle discriminator consists of several biased Schmitt triggers with required amplifiers which channelize the left-right video pulse into angular increments. The output of the azimuth angle discriminator is applied to one input of the appropriate AND gate as previously mentioned.

The range multivibrator consists of five 5-mile multivibrators which are sequentially triggered. The first of the multivibrators is triggered by the trailing edge of the transmitter keying pulse. The output from each of the five multivibrators is applied to the appropriate AND gate.

A pulse from the left-right video discriminator is applied to the discriminator amplifier. If the video pulse is positive, indicating an aircraft to the right of center, it is amplified by the right side discriminator amplifier which uses an npn transistor input circuit. This transistor is biased at zero volt and therefore passes and amplifies only pulses with a positive polarity. The left side discriminator amplifier uses a pnp transistor input circuit biased at zero volt. This circuit passes and amplifies only pulses with a negative polarity. The discriminator amplifier therefore serves as a means of separating or channelizing positive and negative pulses representing aircraft to the right or left of center.

Display Data Processor: Theory of Operation

To separate the left-right video information from the noise, the fore-aft pulse is processed by the fore-aft amplifier and used as a gating pulse to gate only the video through the discriminator amplifiers. The gating circuit consists of a shunt gate which is normally closed and is opened by the positive gating pulse. The output of both the right and left side discriminator amplifier is a negative polarity pulse.

The fore-aft amplifier consists of a biased saturating amplifier that is used to separate the fore-aft pulse from the noise, which is of lesser amplitude, by setting the bias level. When the bias is overcome by the fore-aft pulse, a saturated pulse results which is used as the gating pulse for both the right and the left shunt gate.

There are two Schmitt triggers used for both the left and the right azimuth angle discriminators. The Schmitt triggers are used to convert an analog pulse voltage from the discriminator amplifier, which represents angle, into a digital pulse in the proper channel representing an angular increment.

The Right 30° -Right 60° Schmitt trigger is biased so that it does not fire until the output from the right discriminator amplifier to the Schmitt trigger corresponds to an angle of 30° or greater. When the pulse to the Schmitt triggers

Display Data Processor: Theory of Operation

correspond to an angle between 30° to 60° a negative output pulse is obtained and fed to the five corresponding AND gates of the matrix. When the pulse to the Schmitt triggers corresponds to an angle between 60° to 90° the $R60^{\circ} - R90^{\circ}$ Schmitt trigger fires in addition to the $R30^{\circ} - R60^{\circ}$ Schmitt trigger. The negative output pulse obtained is applied to the five AND gates that are used for the 60° to 90° sector circuitry. A gate from the $R60^{\circ} - R90^{\circ}$ Schmitt trigger circuit is simultaneously fed to the shunt gate of the $R30^{\circ} - R60^{\circ}$ Schmitt trigger circuit to prevent any output from this channel.

The left-right video goes through zero as the threat aircraft passes through zero degree. To simplify the system as well as to obtain positive information in the region about zero degree, it was found advantageous not to use the left-right video to control the illuminating circuitry. Instead the fore-aft pulse is fed to the proper AND gates through an inhibitor circuit. This causes the proper lights ($0^{\circ}-R30^{\circ}, 0^{\circ}-L30^{\circ}$) to be illuminated when a threat aircraft is at zero degree. The normal indications when a threat aircraft is at zero degree are two illuminated lights at the proper range sector.

Display Data Processor: Theory of Operation

When the threat aircraft moves a few degrees to the right of zero degree the left switching amplifier produces an output which is passed through the left OR gate to inhibit or block the fore-aft pulse through the left inhibit gate. In this manner the 0° - $L30^{\circ}$ light is prevented from being turned on.

If the threat aircraft is 30° or more to the right, the output from the $R30^{\circ}$ - $R60^{\circ}$ Schmitt trigger is applied through the right OR gate to inhibit the fore-aft pulse through the right inhibit gate. The 0° - $R30^{\circ}$ light, therefore, is turned off when the threat aircraft is at an angle greater than 30° . The corresponding circuitry for the opposite side operates in a similar manner.

3.2 DETAILED ANALYSIS OF OPERATION

If a threat aircraft is at an angle between 30° and 60° to the right and at a range between 0 and 5 miles the following sequence occurs:

The positive pulse and noise from the left-right discriminator is amplified by Q-1, Q-2, Q-3, and Q-4 of the right-side discriminator amplifier (Fig. 13). The pulse signal is gated out from the noise by means of transistor Q-5 and the gating pulse from the fore-aft amplifier. Q-4 is an emitter follower used to obtain a low impedance output.

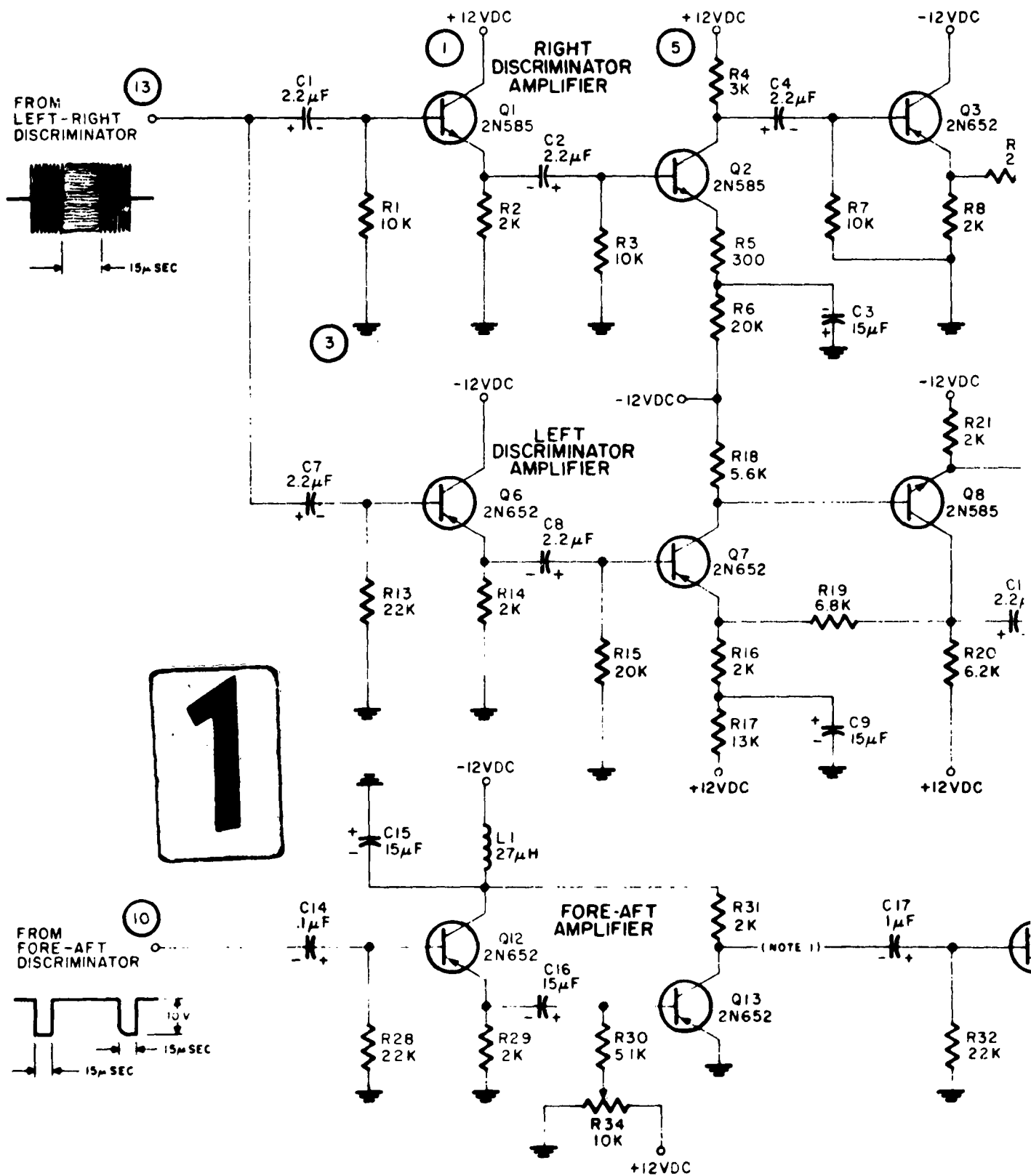
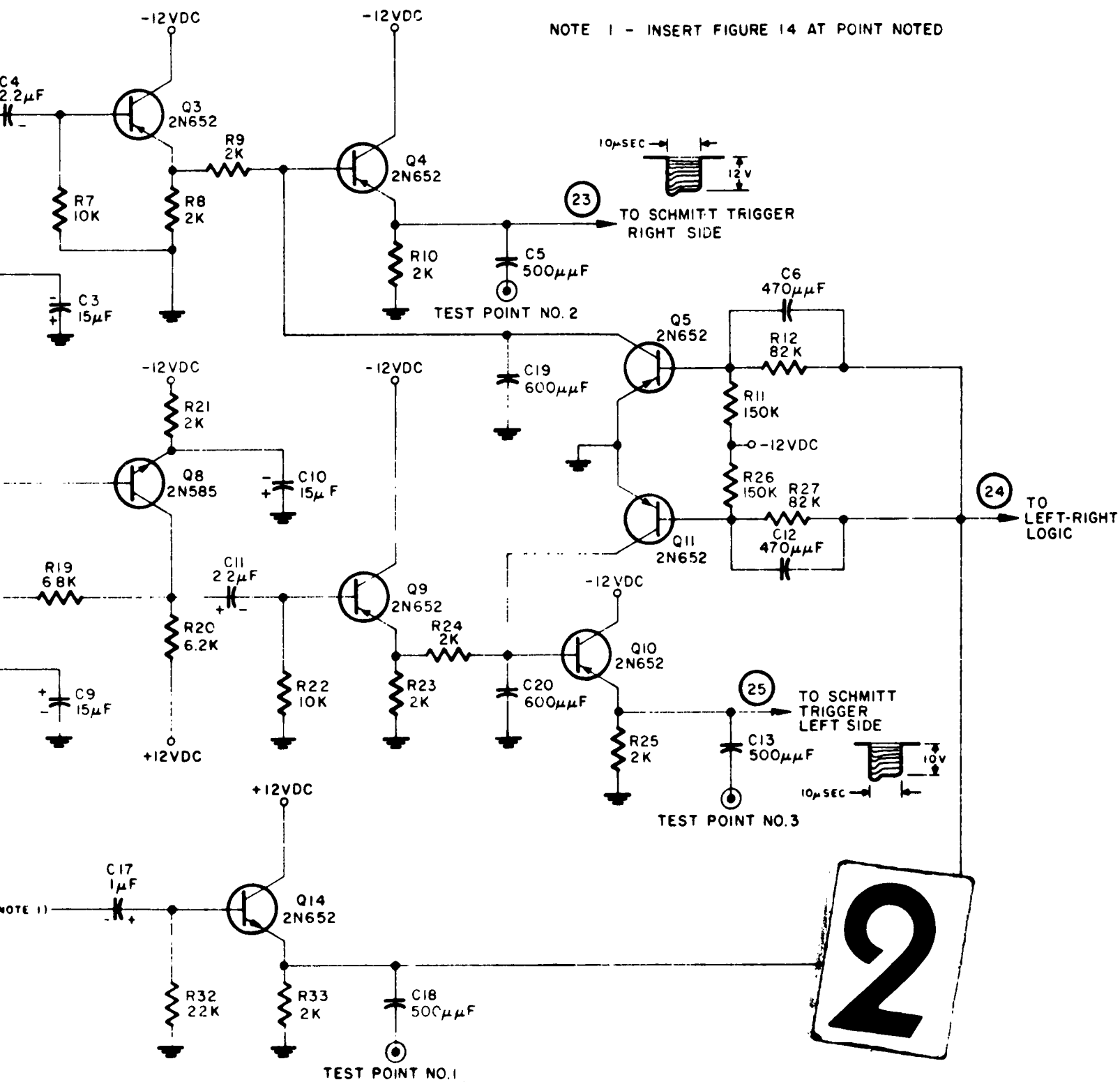


FIGURE 13 - DISCRIMINATOR



E 13 - DISCRIMINATOR AMPLIFIERS

Display Data Processor: Analysis of Operation

Transistor Q-5 is used as a shunt gate. It is normally biased on through R11, the 150,000 ohm resistor in the base circuit. Any signal appearing at the base of Q-4 from Q-3 is shorted to ground by the conduction of Q-5. The noise or undesired signal voltage is dropped across the 2000 ohm resistor R9. When a positive gating pulse is applied to the base of Q-5 through R-12 and C-6 it is cut off and the signal from Q-3, a negative pulse, is permitted to pass through Q-4 and appear at the output of the right side amplifier.

The negative fore-aft pulse is applied to the base of Q-12, an emitter follower, which feeds the biased amplifier Q-13. The off bias on Q-13 is set by potentiometer P-1, which is adjusted by setting the bias level so that the noise which is of lesser amplitude than the fore-aft pulse does not pass through the amplifier. The positive pulse from amplifier Q-13 is a saturated pulse since the gain of the amplifier is at maximum. A fore-aft pulse shaping multi-vibrator (Fig. 14) has been added between Q-13 and Q-14. The output of the fore-aft amplifier is taken from Q-14, an emitter follower.

The negative pulse from the right side discriminator amplifier is applied to the Schmitt trigger angle discriminator as shown in Figure 15. In order not to load down the output

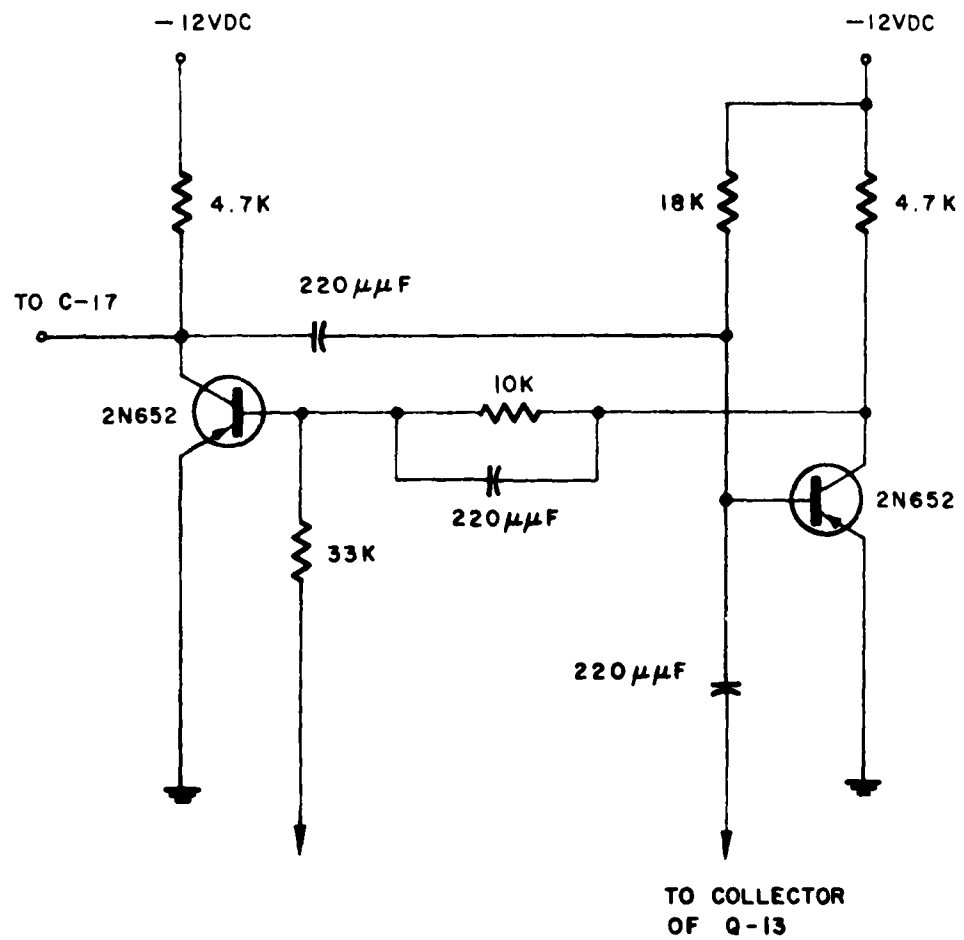
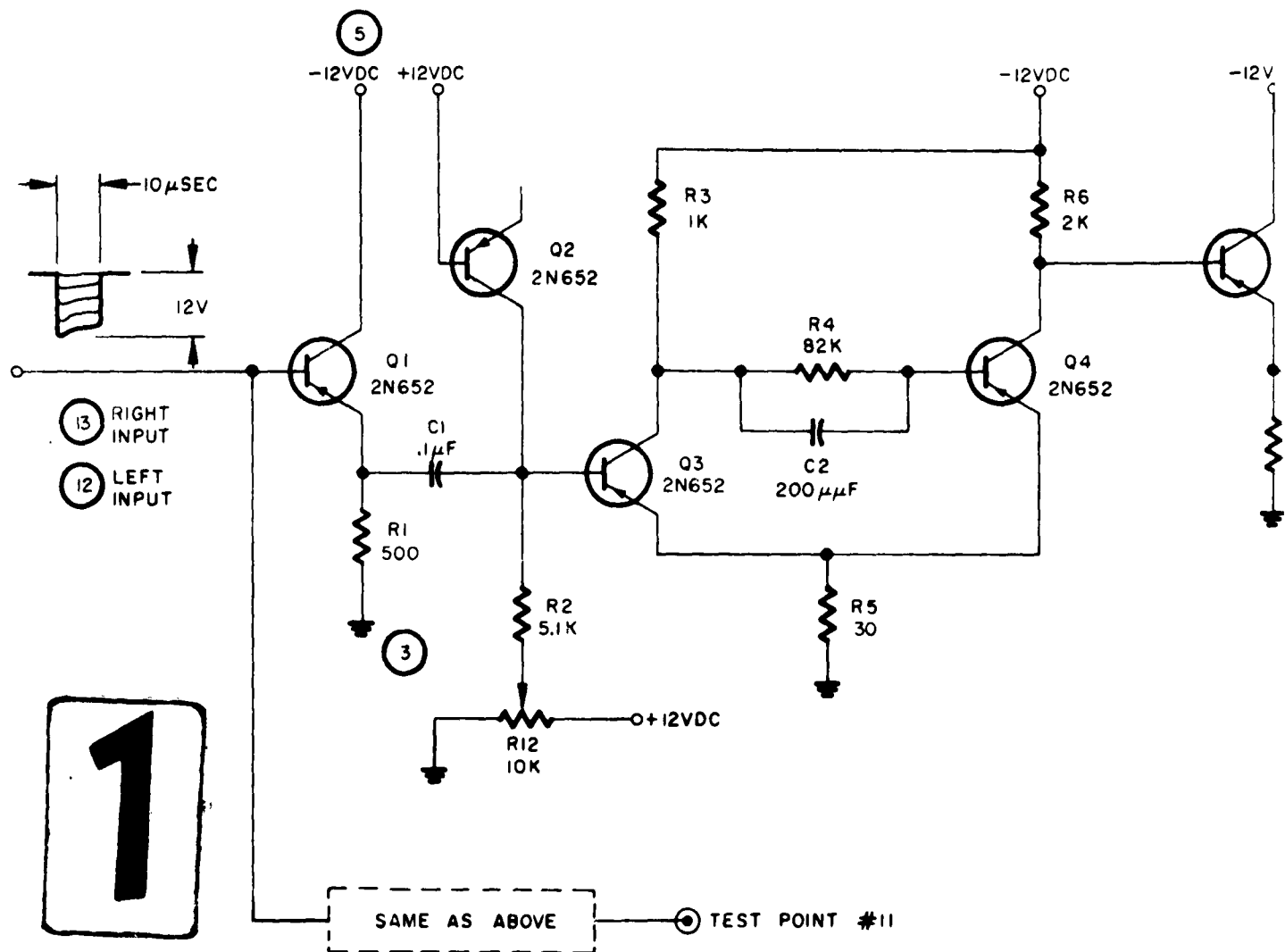


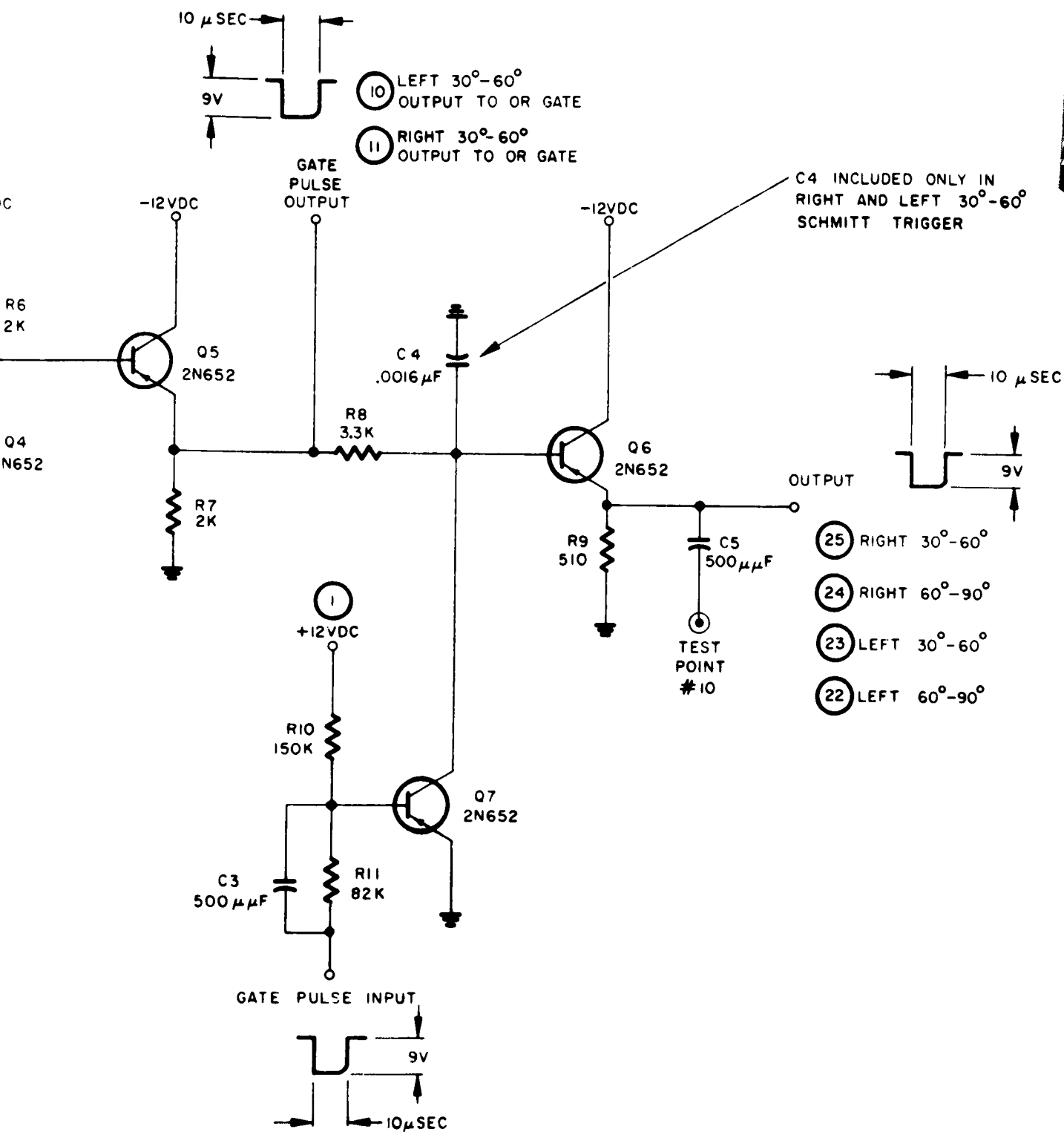
FIGURE 14 - FORE-AFT SHAPING MULTIVIBRATOR



REPEAT ABOVE CIRCUITRY TWICE ON CARD

FIGURE 15 - SCHMITT TRIGGER ANGLE

2



TRIGGER ANGLE DISCRIMINATOR

Display Data Processor: Analysis of Operation

from the discriminator amplifier an emitter follower is used for the input to each Schmitt trigger circuit. The output from the emitter follower feeds the Schmitt trigger which is off biased through resistor R-2 and potentiometer P-1. Potentiometer P-1 is adjusted so that the Schmitt trigger fires at an input voltage pulse from the right side discriminator amplifier which corresponds to an angle of 30° right. The output at the collector of Q-4 of the Schmitt trigger is a negative pulse. The negative pulse from Q-5 is passed through Q-6 and then to the proper AND gates. Shunt gate Q-7 is biased off by means of the voltage applied to the base through R-10. Unless a negative gating pulse is applied to the base of Q-7 the shunt gate stays open and permits an output from the Schmitt trigger. A negative pulse is applied to the base of the shunt gate, to close it, from the $R60^{\circ} - R90^{\circ}$ Schmitt trigger when it fires.

Q-2 is connected as a reversed biased diode with the collector connected to the base of Q-3. The leakage current through Q-2 compensates for the effects of increased I_{cbo} , with temperature, through Q-3 and prevents the firing point of the Schmitt trigger from changing with temperature.

The negative transmitter pulse from the receiver-transmitter unit is used to trigger the range multivibrator as shown in Figure 16. Transistors Q-1 and Q-2 make up the

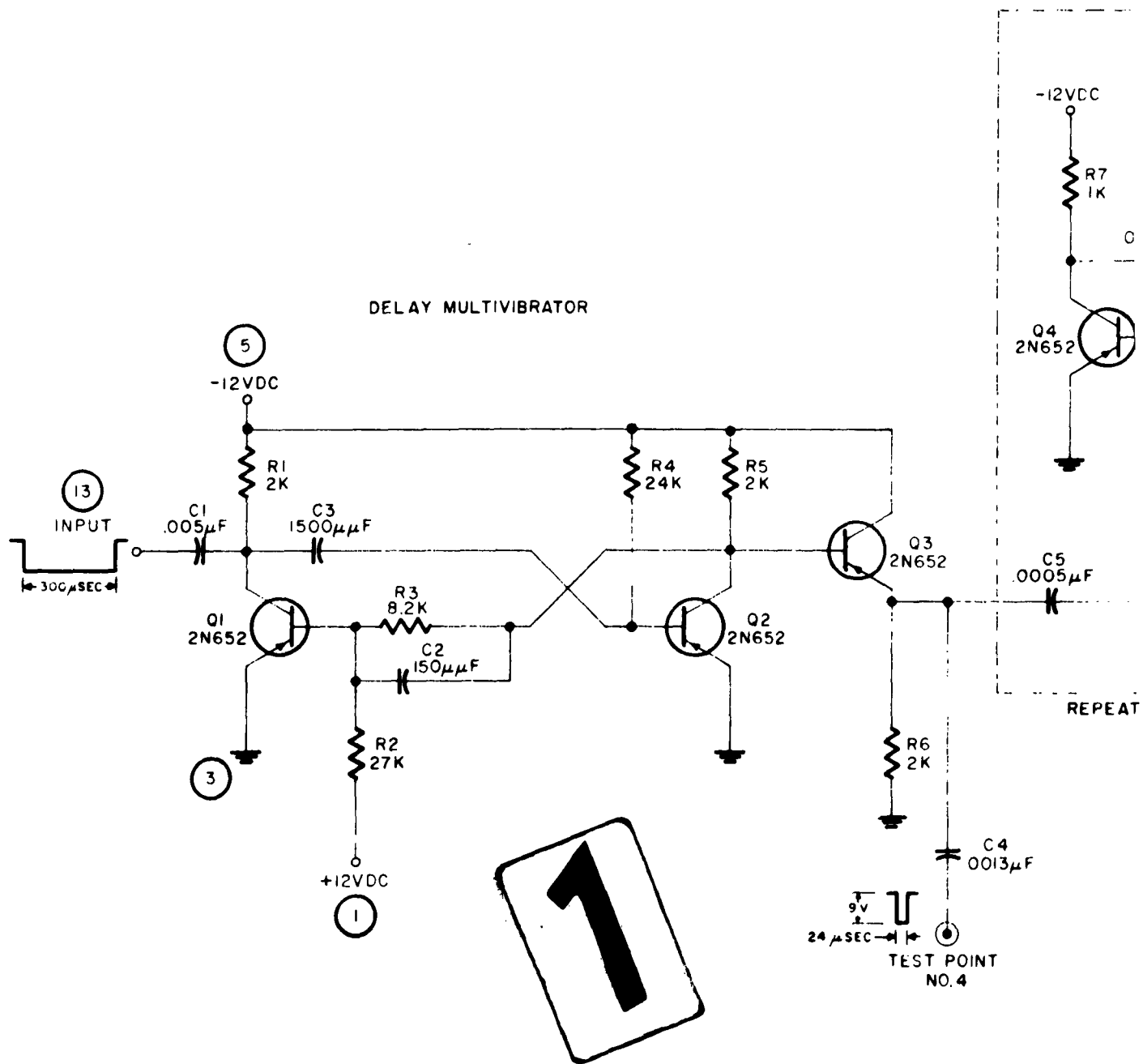
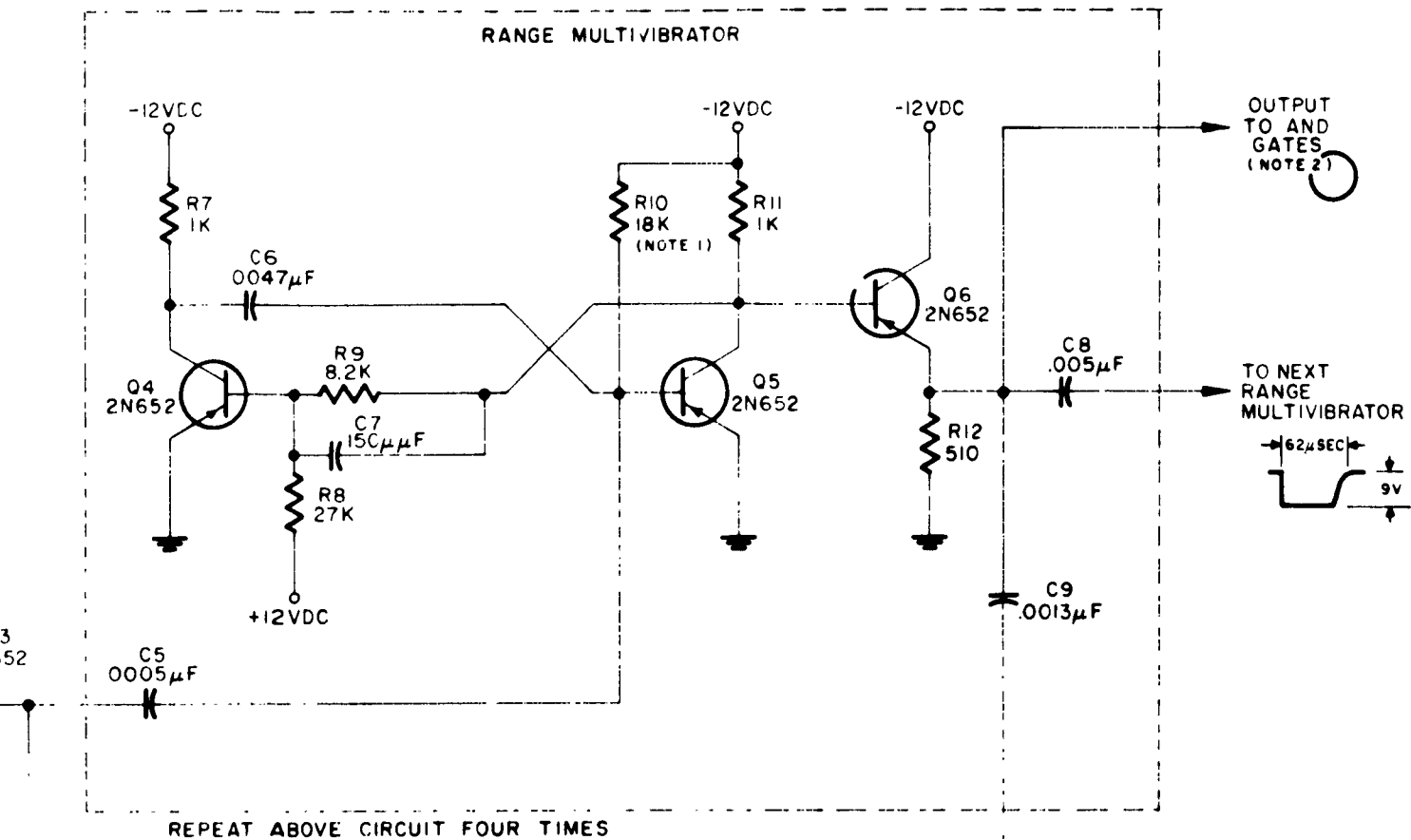


FIGURE 16 - RANGE MULT1



TEST POINT
NO. 5
62μ SEC
9 VOLTS -

NOTES

1 ADJUST FOR 62 μ SECONDS

2	OUTPUT	TERMINAL NO.
	0-5 MILES	20
	5-10 MILES	21
	10-15 MILES	22
	15-20 MILES	23
	20-25 MILES	24

2

16 - RANGE MULTIVIBRATOR

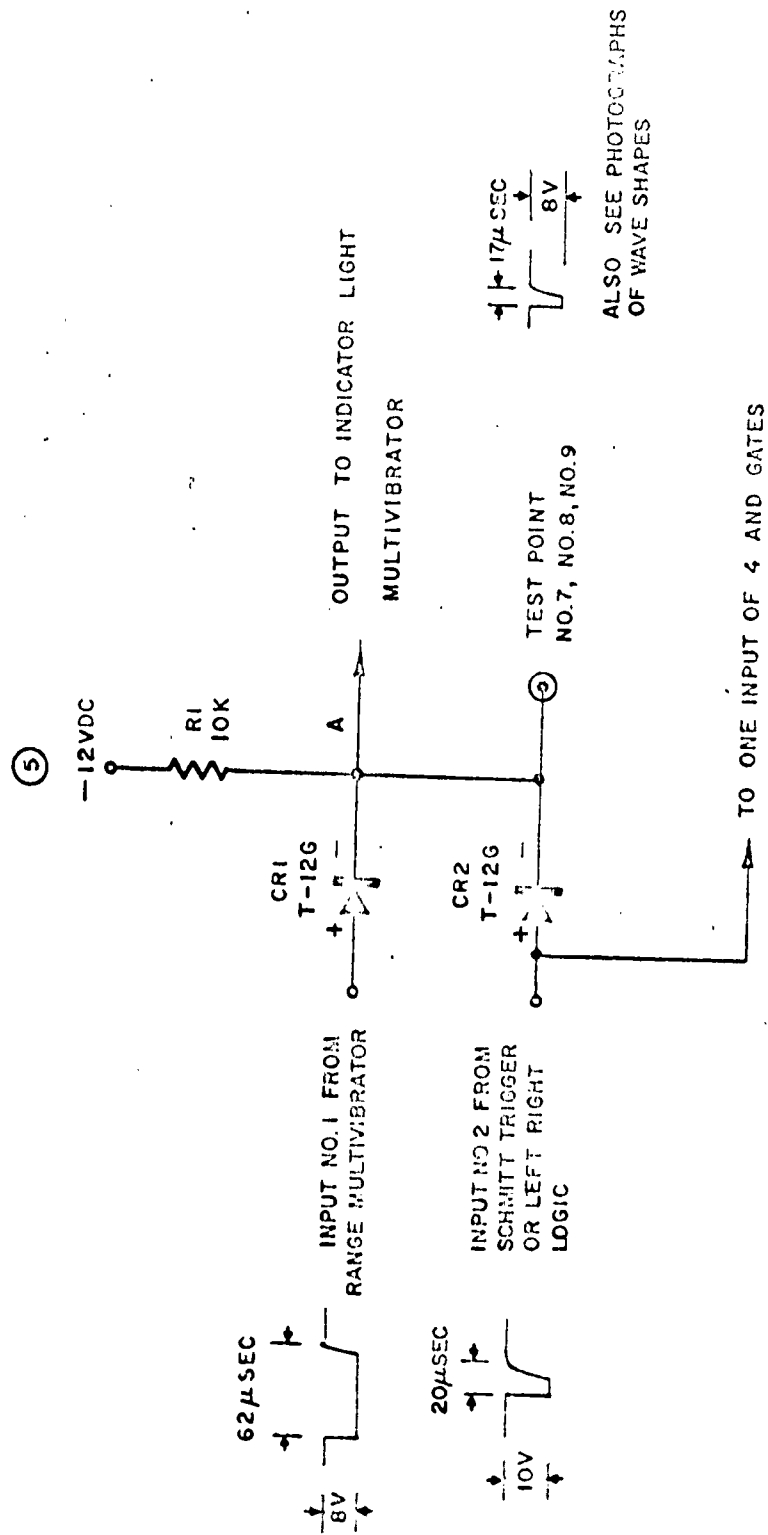
Display Data Processor: Analysis of Operation

delay multivibrators which are used to compensate for the delay of the system in answering an interrogation. The multivibrator is triggered by the lagging edge of the transmitter pulse.

The first 5 nautical-mile range multivibrator consists of Q-4 and Q-5 and is triggered from emitter follower Q-3. An emitter follower has been placed following each multivibrator to prevent loading and also to prevent distortion of the waveshapes. The 0 to 5 nautical-mile multivibrator has a time interval of 62 μ sec which is determined by R10, an 18,000 ohm resistor, and C6, a .0047 μ f capacitor. In some cases due to the tolerance of the timing resistor and capacitor it has been necessary to parallel two resistors for R10 in order to obtain the desired time interval. The four additional 5 nautical-mile multivibrators are a repetition of the first.

The diode AND gates operate as follows (refer to Fig. 17):

When there are no inputs applied to inputs 1 and 2 the two diodes conduct and the potential at point A is close to ground since R1 the 10,000 ohm resistor is large in comparison to the driving emitter follower resistors. When a negative pulse, with an amplitude equal to the supply voltage or sufficient to back bias the diode is applied to input 1 or 2 only, no output results at point A since point A



NOTE: ABOVE CIRCUIT REPEATED 30 TIMES ON CARD.
TEST POINTS ONLY FOR 0-5 MILE AND GATES.

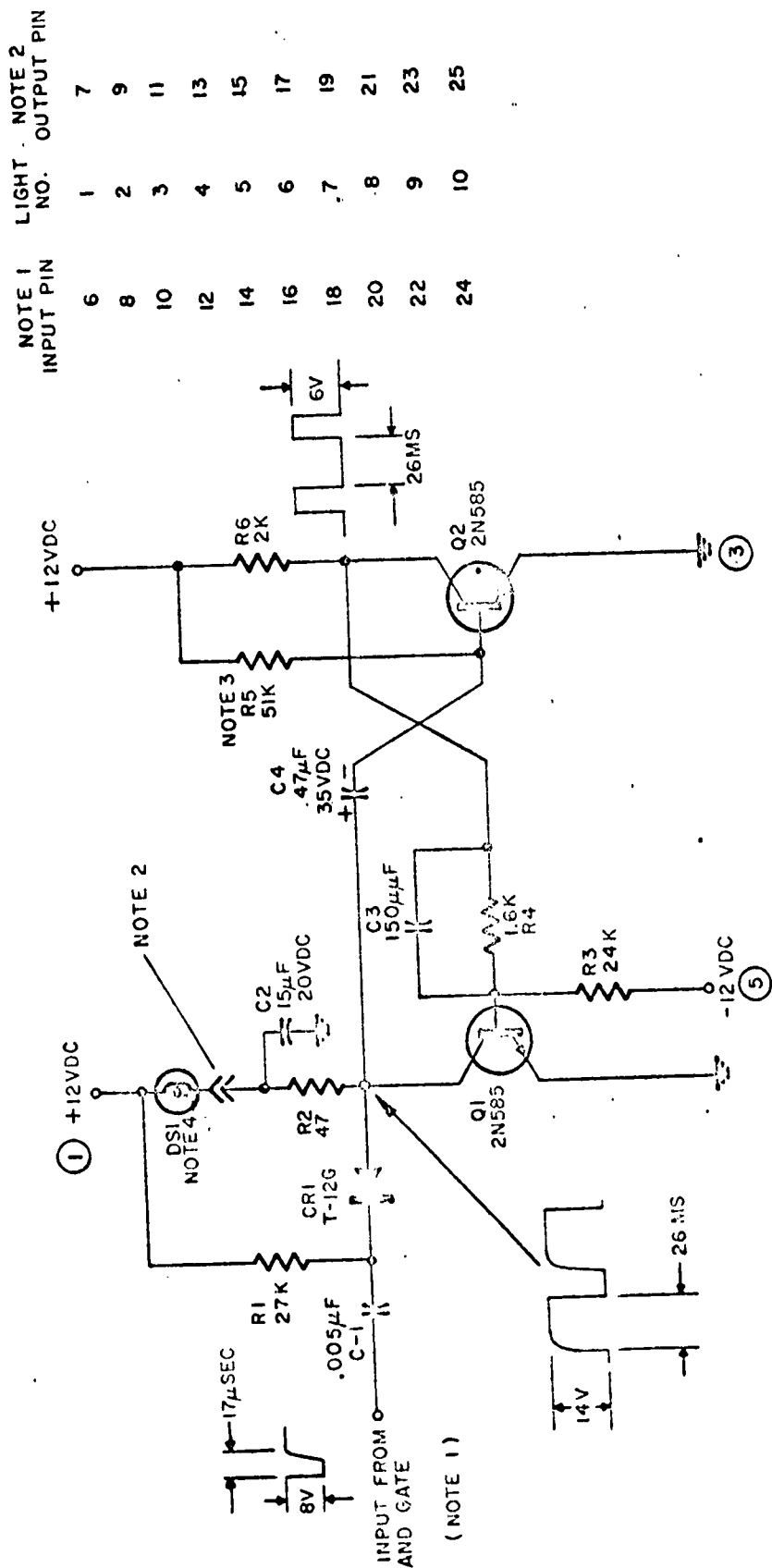
FIGURE 17 - AND GATE

Display Data Processor: Analysis of Operation

is held near ground potential by the conduction of the other diode. However, when negative pulses are applied simultaneously to input 1 and input 2, sufficient in amplitude to back bias both diodes, then a negative pulse occurs at point A. When both diodes are back biased the voltage at point A is the same as the supply voltage or -12 volts. Emitter follower resistances must be low in relation to the value of R1 in order for the AND gate to operate properly.

The negative pulse from the R30° - R60° Schmitt trigger is applied to one input of AND gate No. 6, (see Fig. 12) while the 0 to 5 mile negative range gate is applied to the other input. Coincidence of the two pulses produces a negative pulse at the output of this AND gate. The output of this AND gate goes to the R30° - R60°, 0-5 mile indicator multivibrator.

The prf of the system is 20 cps and to obtain a duty cycle sufficient to light the lamp an indicator multivibrator with a 20 msec period is provided for each lamp. The negative pulse from the AND gate is applied to the collector of Q1 by means of the coupling network consisting of C1 and D1 (Fig. 18). The firing of the indicator multivibrator causes the corresponding lamp to light (Fig. 19) indicating the presence of an aircraft in this sector. Diode D1 acts as a disconnect diode when the indicator multivibrator fires and back biases



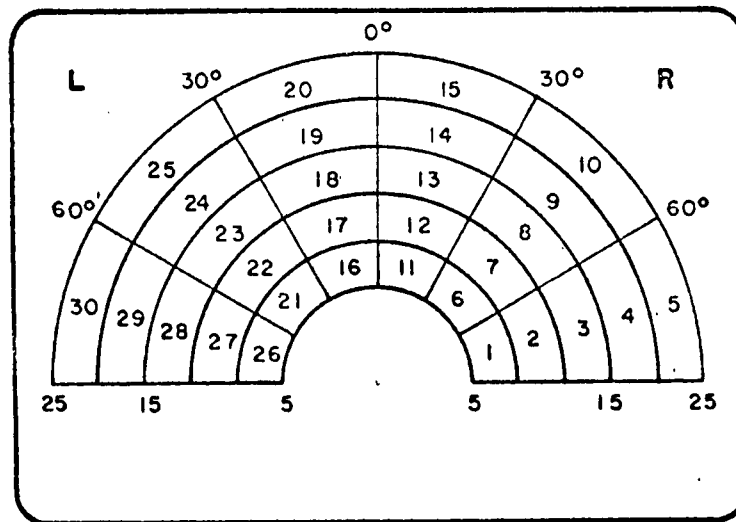


FIGURE 19 - PILOTS WARNING INSTRUMENT DISPLAY

Display Data Processor: Analysis of Operation

the diode. The period of the indicator multivibrator is determined by C4 and R5. The 5-volt indicator lamps draw an average current of approximately 60 milliamperes. Capacitor C2 acts as a decoupling capacitor to prevent intercoupling and undesired firing of the other indicator multivibrators.

If a threat aircraft is at an angle between 60° and 90° to the right and at a range between 0 and 5 miles the following occurs.

The sequence of events for the above condition is similar to those described previously. A positive pulse corresponding to an angle between 60° and 90° is applied to the right side discriminator amplifier (Fig. 12). Except for the fact that the positive video pulse is greater in amplitude, the operation of the right-side amplifier and fore-aft amplifier is the same as previously described. However, the negative pulse, which is applied to the two right-side Schmitt triggers fires both the $30^{\circ} - 60^{\circ}$ and the $60^{\circ} - 90^{\circ}$ Schmitt triggers. (Fig. 15). The negative pulse output from the $60^{\circ} - 90^{\circ}$ Schmitt trigger is applied to the $60^{\circ} - 90^{\circ}$ AND gates. A negative gate from the emitter of Q5 of the $R60^{\circ} - R90^{\circ}$ Schmitt trigger is applied to the base of Q7 of the $R30^{\circ} - R60^{\circ}$ Schmitt trigger by means of

Display Data Processor: Analysis of Operation

R11 and C3. Q7 conducts and prevents an output from being obtained from the emitter of Q6. It is therefore not possible for the $R30^{\circ}$ - $R60^{\circ}$ row of indicator lamps to be illuminated. Coincidence between the output of the $R60^{\circ}$ - $R90^{\circ}$ Schmitt trigger and the 0 to 5 mile range gate at the No. 1 AND gate results in an output. The output from this AND gate triggers the corresponding indicator multivibrator which causes the corresponding lamp to illuminate.

When a threat aircraft is at 0 degree and at a range between 0 and 5 miles, the system operates as follows (Fig. 12).

The positive output from the fore-aft amplifier is applied to the inhibitor gate of the right logic circuitry (Fig. 20) by means of capacitor C5 to diode D5. At zero degree there is no inhibit pulse applied to diode D4 and, since there is zero bias on diode D5, the positive pulse passes through and is coupled to the base of Q3 by C7 and R9. Q3 is an amplifier inverter and provides a negative output pulse. The negative pulse is taken from the emitter of Q4 and applied to the $0 - R30^{\circ}$ AND gates. Coincidence between the negative pulses from Q4 of the left-right logic circuitry and the 0 to 5 mile range gate results in an output from the No. 1 AND gate which triggers the corresponding indicator multivibrator and lamp. The fore-aft pulse is simultaneously applied to the same input of the left logic

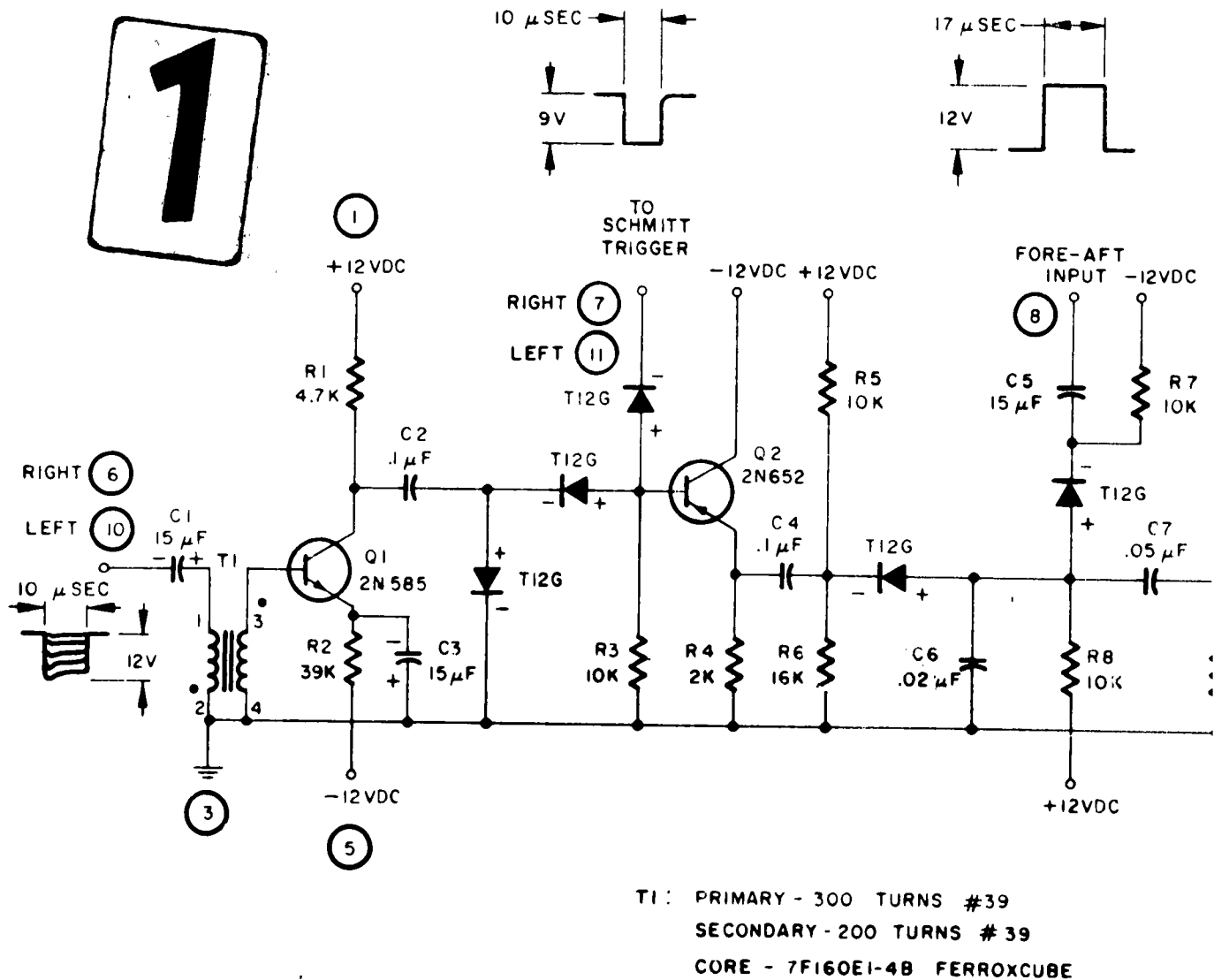
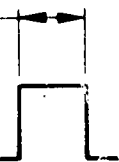
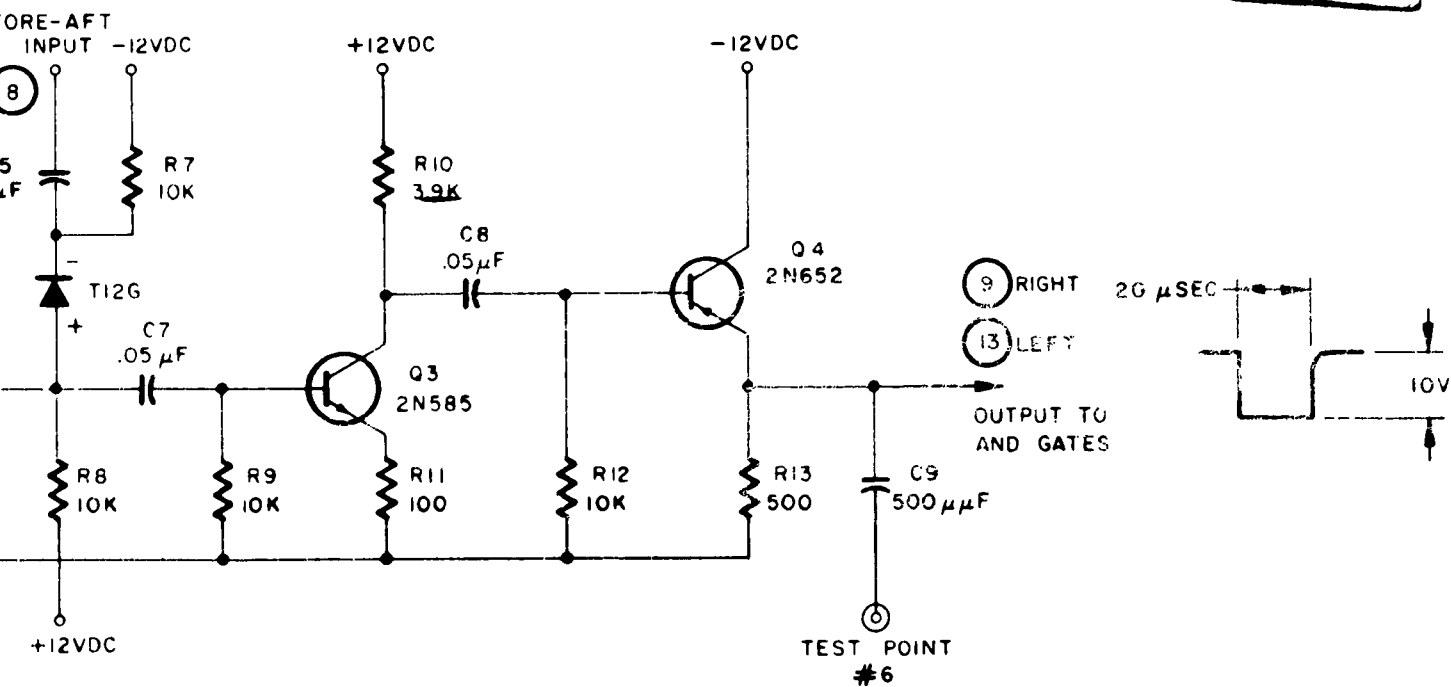


FIGURE 20 - LEFT-RIG



2



9
CUBE

20 - LEFT-RIGHT LOGIC

Display Data Processor: Analysis of Operation

circuitry. The operation of the left logic circuitry is the same as for the right logic circuitry with the exception that it causes the No. 16 lamp to light. When the aircraft is at 0 degree, both the No. 11, and No. 6 lamps are lit.

When a threat aircraft is between 0° and 30° to the right and at a range between 0 and 5 miles, the following occurs.

The negative pulse output from the left discriminator amplifier is applied to terminal 10 of the left logic circuitry. The pulse is inverted by transformer T1 and amplified by Q1, (Fig. 20). The negative pulse from the collector of Q1 is applied to one input of the OR gate. The negative pulse from the OR gate passes through emitter follower Q2 to the inhibitor gate where it inhibits or blocks the fore-aft pulse. The negative pulse from Q2, the emitter follower, causes diode D4 to conduct through R8, a 10,000 ohm resistor. This causes a voltage drop across R8 and prevents a positive pulse from being developed across it. The positive fore-aft pulse is thus inhibited or blocked and no output is obtained from the left logic circuit. The 0° - $L30^{\circ}$ row of lights therefore are not illuminated. However, the right-side logic circuit does not receive an input at terminal 6 and therefore no inhibit pulse is generated. An output is obtained from the right logic circuit, as described and the No. 11 lamp is turned on.

Display Data Processor: Analysis of Operation

The operation of the system when the threat aircraft is at other angles and ranges is similar to the previous examples described.

3.3 POWER SUPPLY

A transistorized dc-to-dc converter is used to convert the positive 27.5 volts dc, from the aircraft, to a negative 12 volts dc. The converter is essentially a switch, a transformer, and a rectifier (Fig. 21).

The +12 volt dc regulator (Fig. 22) is a conventional type which lowers and regulates the +28 volts input to +12 volts. It makes use of a differential amplifier, which has good temperature stability, to amplify the voltage change sensed at the base of Q5. The reference voltage for the differential amplifier is obtained by means of resistor R5 and Zener diode D2. A separate regulated voltage is provided for the collector of Q5 which provides better regulated 12-volt output at the cost of only two additional components, R1 and D1. The 510-ohm resistor in the base circuit of Q4 has been added to obtain better temperature stability. Emitter follower Q3 is controlled by the differential amplifier output. It, in turn, drives emitter follower Q2 which drives emitter follower Q1. Three emitter followers are required to obtain sufficient current amplification to regulate up to one ampere through Q1.

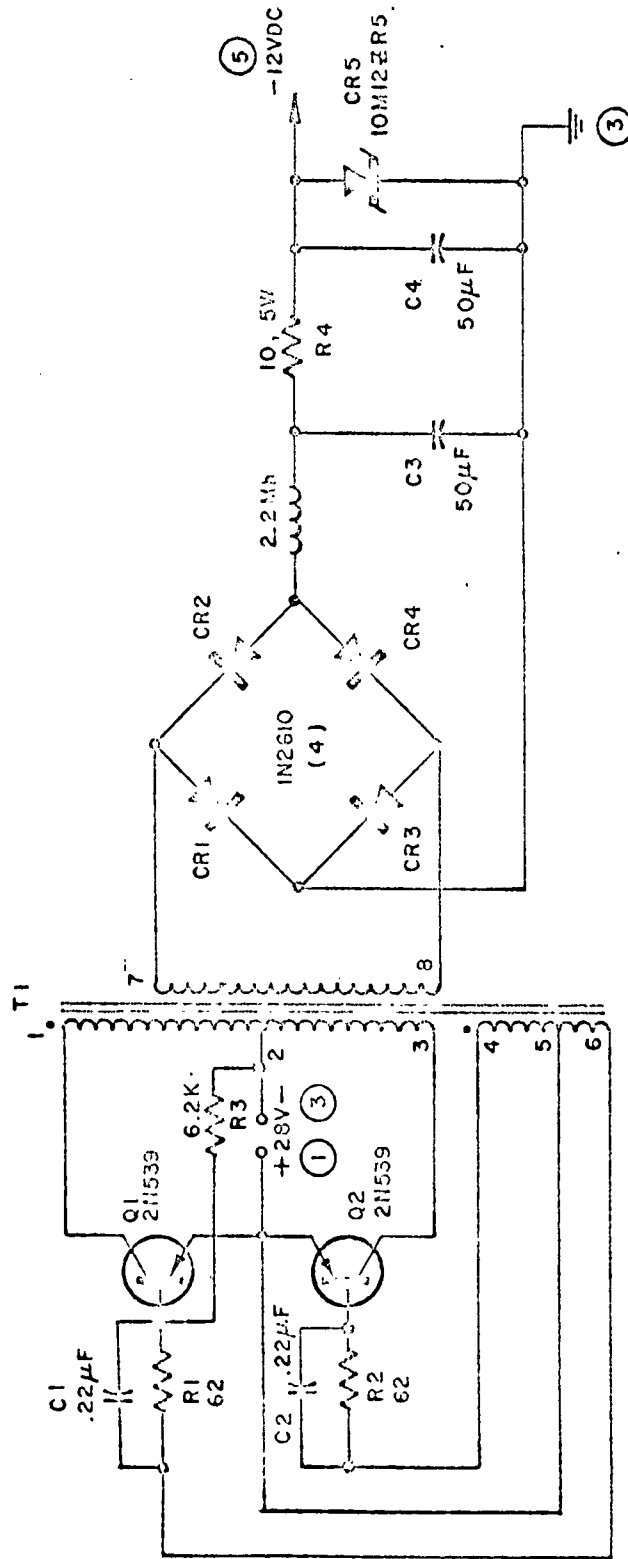


FIGURE 21 - DATA PROCESSOR NEGATIVE 12 VOLT POWER SUPPLY

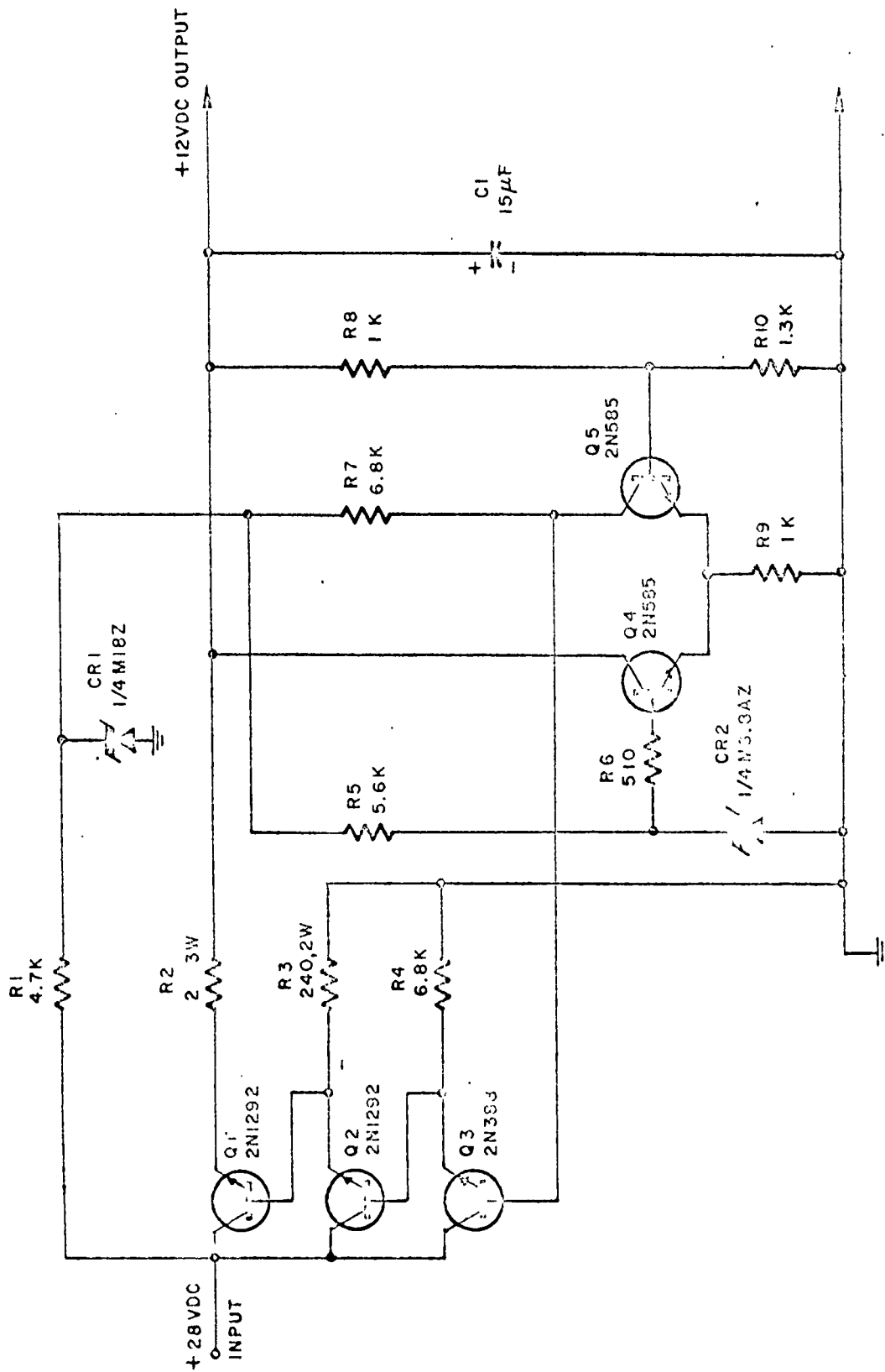


FIGURE 22 - POSITIVE 12-VOLT REGULATOR

4. RECOMMENDATIONS

The Pilot Warning Instrument system development program has culminated in an equipment design suitable for test and experimentation. Due to limited resources certain areas of design were not carried to a refined level of development.

Further effort should be expended in improving the receiver phase characteristics over a wider range of dynamic signal level. This would embody an improved first intermediate frequency amplifier, and an improved design for the second intermediate frequency limiters. The frequency of the second intermediate frequency amplifier should be increased to permit use of a shorter reply pulse. The higher frequency would facilitate good phase determination in a shorter time than is presently used.

An important parameter in the Motorola system concept, the altitude parameter, could not be fully developed at this time. The altimeter transducers require greater precision than was available at that time from aneroid bellows manufacturers at reasonable cost. Consequently the present altitude transducers are only good enough to demonstrate the principle or method of establishing the altitude parameter.

Further development of the altitude transducer would provide a device capable of precision measurement of pressure altitude in terms of frequency. This improved device would permit the require performance of the altitude parameter in

Recommendations

the Pilot Warning Instrument system. Application of this altitude transducer would not be restricted to the Pilot Warning Instrument system, but could also provide altitude data to other systems requiring accurate determination of pressure altitude.

A further evolution of the Pilot Warning Instrument should, if possible, embody the use of shorter reply pulses to reduce the annular interference problem from simultaneous replies. This would require an increase in bandwidth determined by the pulsewidth. With improved semiconductor technology many of the complex functions of the Pilot Warning Instrument system could be further miniaturized and simplified with improved reliability. Some of the vacuum tubes employed in the transmitter may be eliminated with the availability of new and improved semiconductor devices.

The display portion of the present system was designed to provide a display unit which was no larger than a standard aircraft instrument. The quantized display is capable only of showing the general region of occupancy of an intruding aircraft. Data generated by the Receiver-Transmitter unit is of higher accuracy and resolution than this display is capable of presenting to a pilot.

Recommendations

Display of this type of data to a pilot should be accomplished in a positive manner without a panic possibility. The design of such a display must necessarily result from a cockpit human factor study followed by the required electronic design.

APPENDIX 1 - TESTPOINT WAVESHAPES

The waveshapes shown here were obtained at the testpoints and other key points of the data display processor box. Also included are the horizontal sweep speed and the vertical sensitivity of the oscilloscope used in obtaining the information. These waveshapes should be helpful in understanding the data display processor circuitry and helpful in trouble location.

Appendix 1 - Testpoint Waveshapes

NOTE: SWEEP SPEED: $10\mu\text{SEC}/\text{CM}$
VERTICAL SENSITIVITY $5\text{V}/\text{CM}$



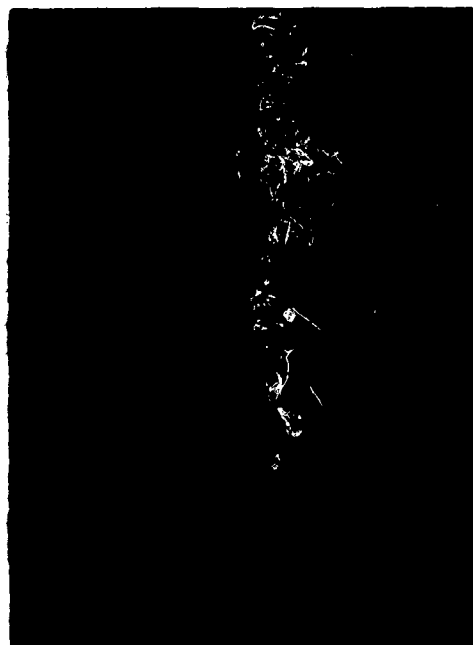
TP NO 3 LEFT GATE VIDEO
THREE DIFFERENT VIDEO LEVELS

DISCRIMINATOR AMPLIFIER CARD



TP NO 4 DELAY PULSE
(ADJUSTED TO $22\mu\text{SEC}$)

RANGE MULTIVIBRATOR CARD



TP NO 1 FORE-AFT PULSE

DISCRIMINATOR AMPLIFIER CARD

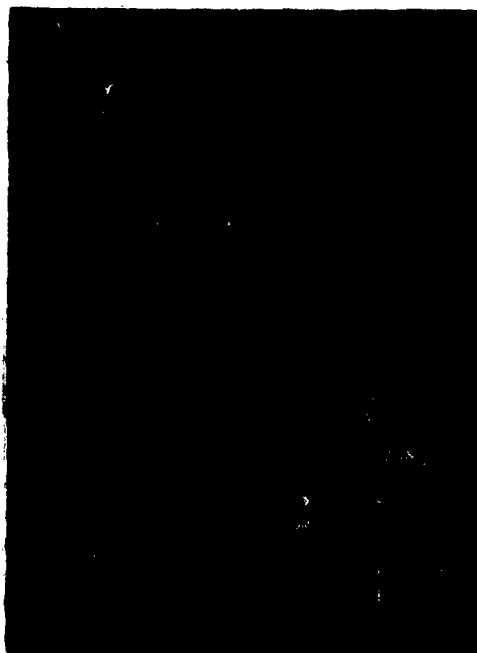


TP RIGHT GATED VIDEO
THREE DIFFERENT VIDEO LEVELS

DISCRIMINATOR AMPLIFIER CARD

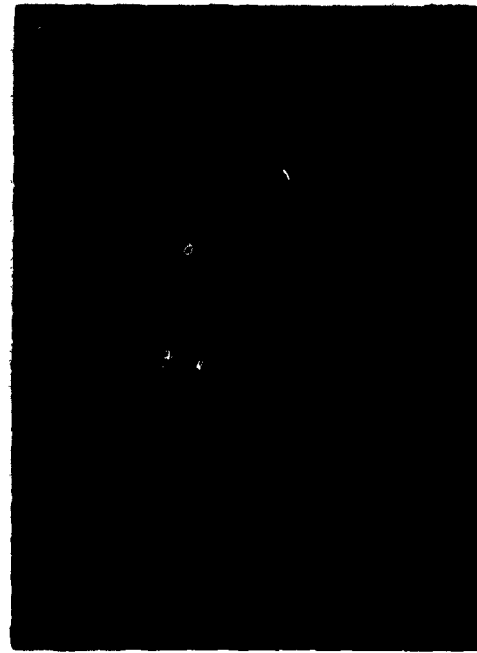
Appendix 1 - Testpoint Waveshapes

NOTE. SWEEP SPEED. $10\mu\text{SEC/CM}$ } FOR ALL WAVESHAPES
 VERTICAL SENSITIVITY 5V/CM }



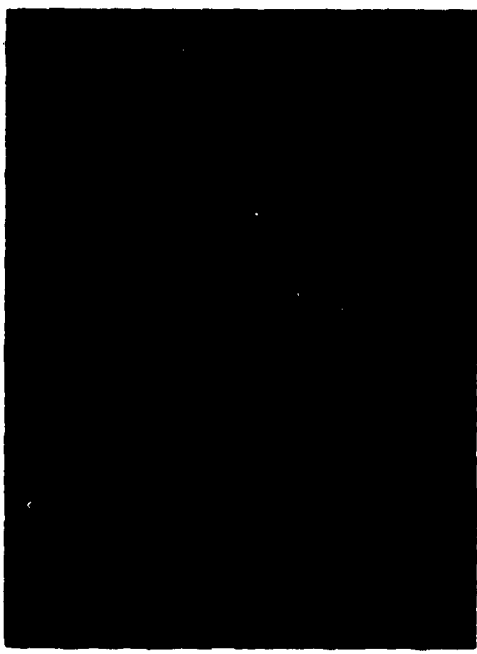
T.P. NO. 7 0-30°R AND GATE OUTPUT
 T.P. NO. 7 0-30°L AND GATE SAME

AND GATE CARD



T.P. NO. 8 30°L-60°L AND GATE OUTPUT
 30°R-60°R AND GATE SAME

AND GATE CARD



T.P. NO. 5 FULL RANGE VV OUTPUT
 5-10, 10-15, 15-20, 20-25, RG MV OUTPUT SAME

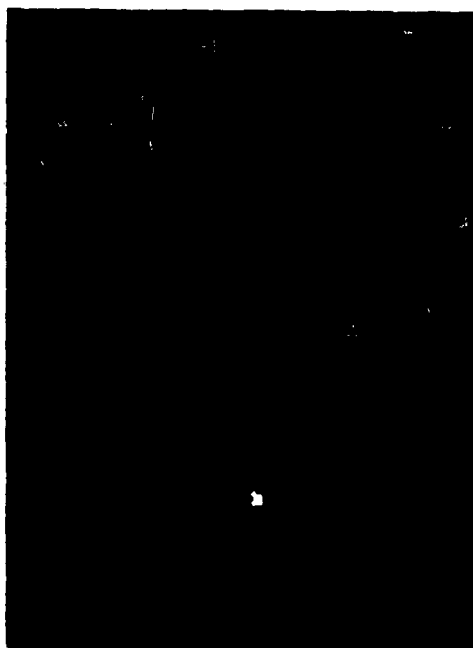
RANGE MULTIVIBRATOR CARD



T.P. NO. 6 LEFT-GATE PULSE
 RIGHT-GATE SAME

LEFT-RIGHT LOGIC

Appendix 1 - Testpoint Waveshapes

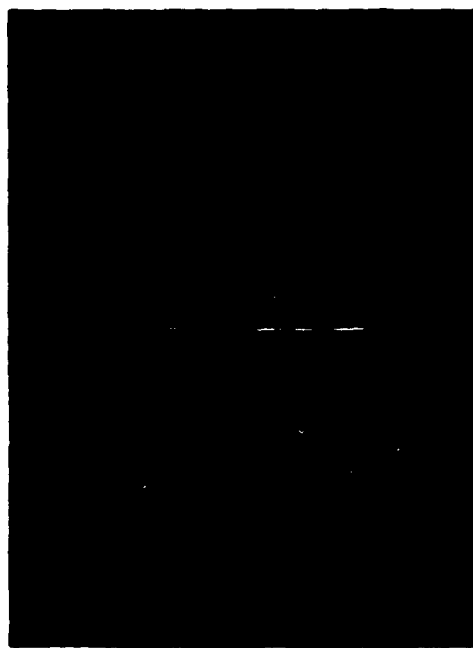


NOTE:

SWEEP SPEED = 10μ SEC/CM
VERTICAL SENSITIVITY 5V/CM

T.P. NO. 11 60°L-90°L SCHMITT TRIGGER OUTPUT
T.P. NO. 11 60°R-90°R SCHMITT TRIGGER SAME

SCHMITT TRIGGER CARD



T.P. NO. 9 60°L-90°L AND GATE OUTPUT
T.P. NO. 9 60°R-90°R AND GATE SAME

AND GATE CARD



T.P. NO. 10 30°L-60°L SCHMITT TRIGGER OUTPUT
T.P. NO. 10 30°R-60°R SCHMITT TRIGGER SAME

SCHMITT TRIGGER CARD

Appendix 1 - Testpoint Waveshapes

NOTE: SWEEP SPEED: .2 msec/CM FOR ALL WAVESHAPES



BOTTOM: BASE OF Q-1 OR Q-2
TOP: COLLECTOR OF Q-1 OR Q-2
VERTICAL SENSITIVITY 20V/CM

DISPLAY POWER SUPPLY



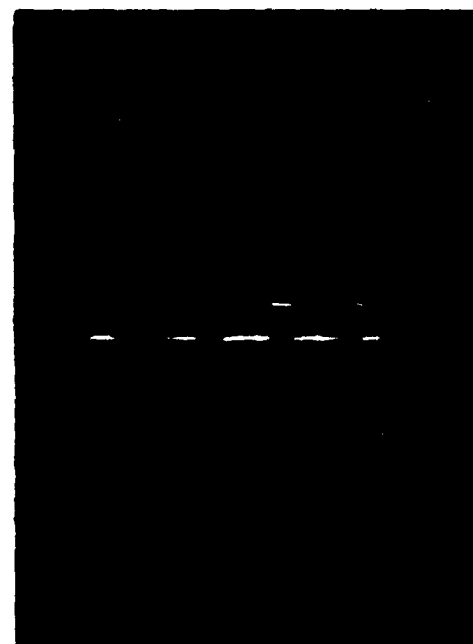
PIN NO. 7 OR NO. 8 OF T-1
VERTICAL SENSITIVITY 10V/CM

DISPLAY POWER SUPPLY



COLLECTOR OF Q-1
VERTICAL SENSITIVITY 5V/CM

INDICATOR MULTIVIBRATOR CARD



COLLECTOR OF Q-2
VERTICAL SENSITIVITY 5V/CM

INDICATOR MULTIVIBRATOR CARD

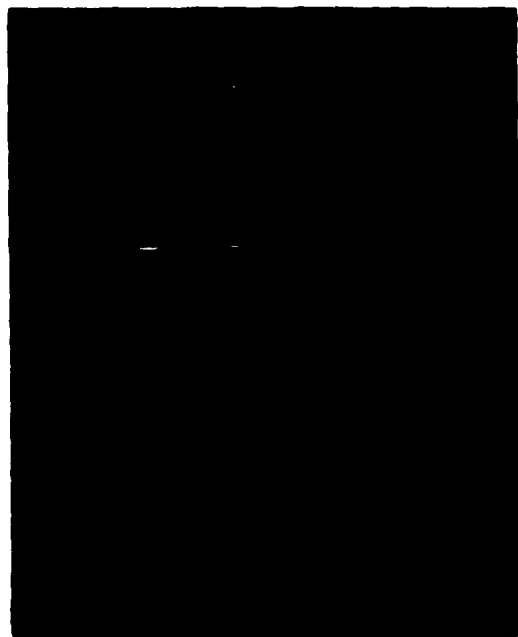
Appendix 1 - Testpoint Waveshapes



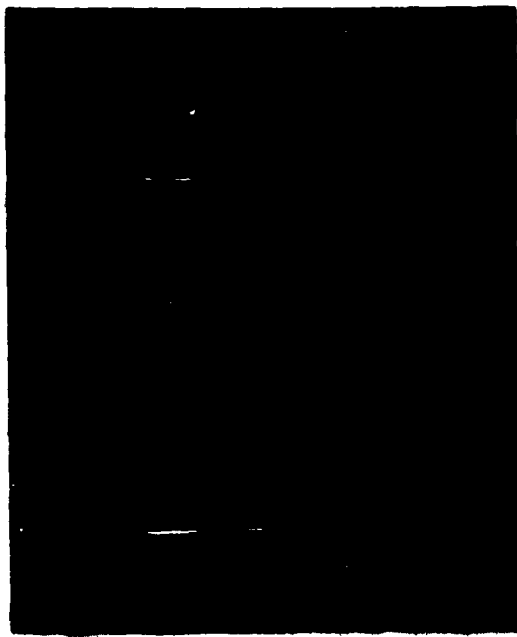
0 DEGREES
30 DEGREES LEFT



60 DEGREES LEFT
90 DEGREES LEFT



0 DEGREES
30 DEGREES RIGHT

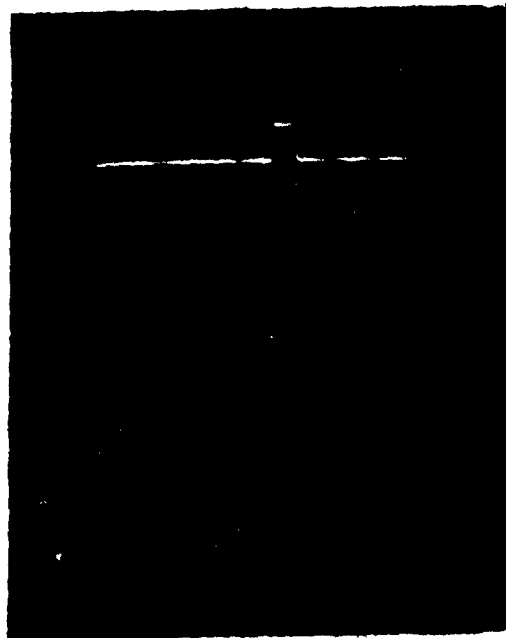


60 DEGREES RIGHT
90 DEGREES RIGHT

Time base 20 μ sec/cm
Vertical 1 volt/cm

GATE AND VIDEO OUTPUTS FROM DISCRIMINATORS

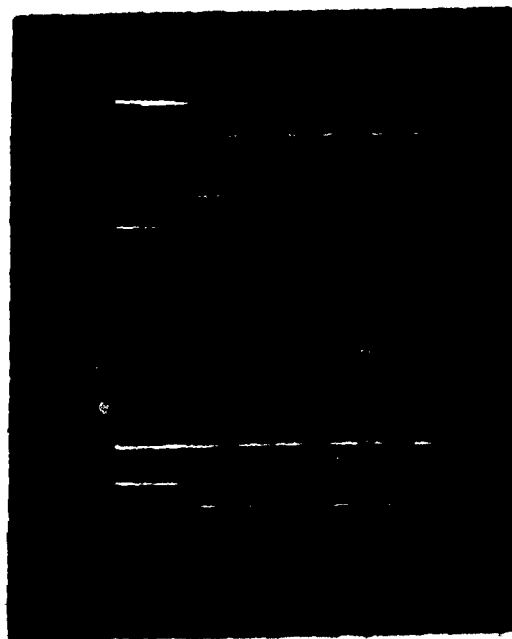
Appendix 1 - Testpoint Waveshapes



15 μ sec

REPLY PULSE

Time base 20 μ sec/cm
Vertical 10 volts/cm



300 μ sec KEYER PULSE

300 μ sec DISPLAY TIMER

REPLY TRIGGER PULSE

300 μ sec MODULATOR PULSE

Time base 100 μ sec/cm
Vertical 10 volts/cm

PROGRAMMER TESTPOINT SIGNALS